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# **Coaxial Reference Standard for Microwave Power**

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## **TRADE NAME and SI UNITS DISCLAIMER**

Certain commercial components used in the reference standard are identified in this document in order to adequately specify the design. Such use and identification does not imply recommendation or endorsement by NIST nor does it imply that the identified items are necessarily the best available for the purpose.

The International System of Units (SI) is used except in the dimensioned part drawings found in Appendix B. The shop which made these parts was not equipped to use metric dimensions. Economic resources are not currently available to convert the drawings to SI units.



# COAXIAL REFERENCE STANDARD for MICROWAVE POWER

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Design and construction details are given for the bolometer (thermistor) mounts used by NIST as working reference standards for microwave power calibrations in coaxial transmission line. The effective efficiency of these reference standards can be measured directly in the NIST coaxial microcalorimeters. The standards are then used to calibrate other microwave power sensors. Two versions are described: one with a Type N connector and one with an APC-7 connector. The operating frequency range is 0.05 to 18 GHz with either connector. Detailed drawings and performance measurements are included.

Key words: bolometer mount; coaxial thermistor mount; microwave; microwave power measurement; microwave reference standard; thermistor mount

## 1. INTRODUCTION

### 1.1 NIST Microwave Power Standards

The microwave power standards in use at the National Institute of Standards and Technology (NIST) consist of microcalorimeters and associated reference standards [1-4]. Each power standard is made up of both a microcalorimeter and a reference standard. The reference standards are substitution type bolometric power detectors.<sup>1</sup> Commercial bolometer mounts, especially coaxial units, are generally not suitable for use as the reference standard. While they have been used by NIST in the past, the resulting calibration uncertainties were higher because of it.

To meet the need in the microwave community for lower calibration uncertainty, a reference standard designed for use with the microcalorimeter is required. This technical note describes two coaxial bolometer mounts that have features giving optimum performance with the microcalorimeter. Figure 1.1 shows the coaxial microcalorimeter and the Type N thermistor mount used as the reference standard. Design and construction details for the coaxial microcalorimeter may be found in reference [5]. This reference and those noted previously all include detailed descriptions of the microcalorimeter and bolometer mount operation. However, for convenience a brief summary follows.

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<sup>1</sup>These detectors are generally called bolometer mounts or simply, mounts. In this document, the terms "reference standard," "bolometer mount," and "mount" are used interchangeably.

## 1.2 Bolometer Mount/Microcalorimeter Operation

The bolometric power detector uses a heat sensitive resistor (bolometer) which terminates the transmission line and absorbs the microwave energy. Two types of bolometers are used: a platinum wire with a positive temperature coefficient called a barretter, and a thermistor bead with a negative temperature coefficient. The detectors are biased by an external source of dc current (power meter) to an operating resistance that produces a match with the characteristic impedance of the transmission line. Coaxial mounts typically use two bolometer elements which are connected in series for the dc bias, but are in parallel for the rf. Thus, to match the 50  $\Omega$  characteristic impedance of a coaxial transmission line, the pair is maintained at a series resistance of 200  $\Omega$ . When microwave energy is applied to the mount, the dc bias supplied by the power meter is automatically reduced to maintain a constant operating resistance [6]. If all the microwave energy incident on the mount were absorbed by the bolometer elements and if the elements were heated identically by equal amounts of dc and rf power, then the microwave power would be equal to the amount by which the dc power is reduced. This is called a substitution type power meter, because the rf power replaces a portion of the dc bias power. The substituted dc power (also called the bolometric power) is calculated using the equation

$$P_{dc} = \frac{V_1^2 - V_2^2}{R_0}, \quad (1.1)$$

where  $V_1$  is the power meter output voltage (the dc voltage across the bolometer elements) with no rf,  $V_2$  is the power meter output voltage with rf, and  $R_0$  is the dc operating resistance of the bolometer pair (200  $\Omega$  for a coaxial mount).

The microwave energy incident on a mount is not all absorbed by the bolometer elements. The dielectric and conductor losses in the input connector, the input transmission line, and the bolometer mounting structure result in a measurement error characterized by a correction factor called the mount efficiency. This correction is always less than unity. In addition, the bolometer elements are not heated identically by equal amounts of rf and dc power. This is known as the rf-dc substitution error. The combination of these two effects, which is measured by the microcalorimeter, is a correction factor defined as the effective efficiency  $\eta_e$ . The rf power absorbed by the mount

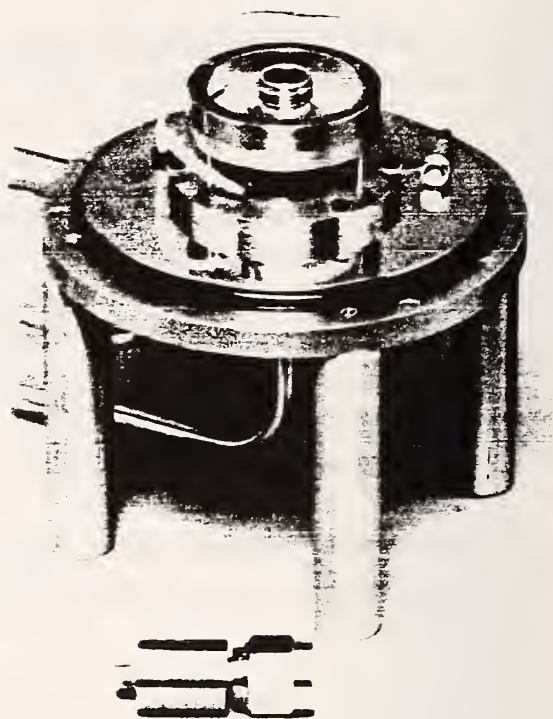


Figure 1.1 Microcalorimeter and coaxial reference standard.



is calculated by dividing the substituted dc power by the effective efficiency. The effective efficiency of the mount is independent of mismatch corrections, which are treated separately at the time of calibration transfer to an unknown mount.

The bolometer elements used in this application are thermistors. Thermistors are rugged and resist burnout in the event of an rf overload. They are available commercially as a conveniently usable subassembly. Disadvantages to using thermistors include a continuous drift in the bias current even in a constant temperature environment. Also, thermistors are not usable in an alternative efficiency measurement technique known as the impedance method [7].

The microcalorimeter essentially measures the temperature rise of the bolometer mount connected to it. In the coaxial microcalorimeter, the temperature increase of the mount is measured with a thermopile. During the measurement, the microcalorimeter is immersed in a stable temperature-controlled water bath [8, 9] to minimize the effect of external temperature changes. The measurement determines the following at each frequency of interest: the power meter and thermopile output voltages ( $V_1$  and  $e_1$ ) with only dc applied to the mount, and then again ( $V_2$  and  $e_2$ ) with both rf and dc applied. The effective efficiency  $\eta_e$  is calculated at each frequency using the equation

$$\eta_e = g \frac{1 - \left( \frac{V_2}{V_1} \right)^2}{\frac{e_2}{e_1} - \left( \frac{V_2}{V_1} \right)^2}. \quad (1.2)$$

The term  $g$  is a frequency dependent correction factor for the microcalorimeter-bolometer mount combination. It is also known as the calorimetric equivalence correction. The uncertainty in the measurement is determined primarily by the uncertainty in  $g$ . The determination of  $g$  is a major effort that is described in reference [10].

A typical reference standard calibration is done at approximately 125 frequencies from 50 MHz to 18 GHz. Even with an automated system, the measurement takes about 40 h. Figure 1.2 shows a typical thermopile output at a few frequencies. The value of  $\eta_e$  for one of the reference standards, measured at 125 frequencies, is shown in figure 1.3. The systematic and total uncertainty in the  $\eta_e$  measurement as a function of frequency is shown in figure 1.4. Details of the automated measurement system and the uncertainty analysis are found in reference [10].

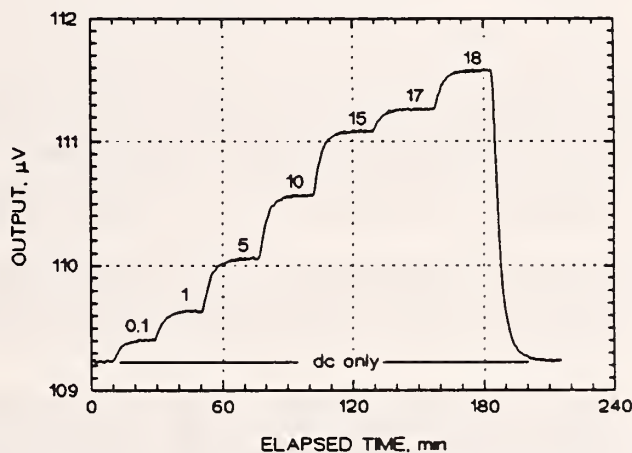


Figure 1.2 Thermopile output versus time for seven frequencies (in GHz).

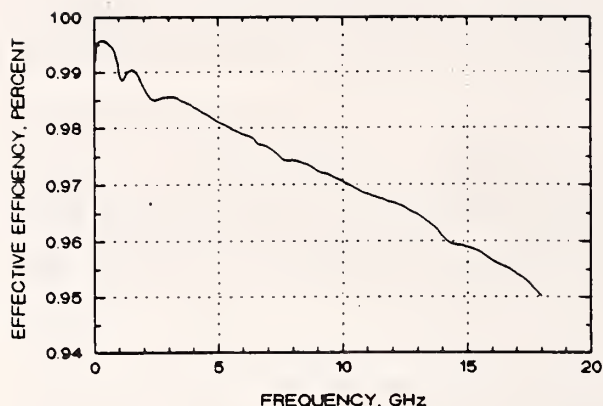


Figure 1.3 Type N mount effective efficiency measured at 125 frequencies.

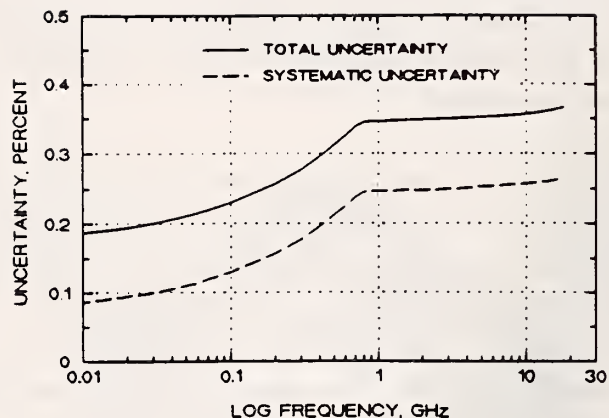


Figure 1.4 The total and systematic uncertainties for the Type N coaxial microcalorimeter when measuring the effective efficiency of a NIST Type N mount.

## 2. DESIGN CONSIDERATIONS and DECISIONS

The features of the bolometer mount described below are both desirable and necessary for the mount to be used as an optimum reference standard. The body of the mount and the internal thermistor bead assembly are both considered.

### 2.1 Mount Material

As noted in the introduction, the primary function of the microcalorimeter is to measure the effect of all microwave energy dissipated in the mount. To best accomplish this there should be minimal thermal resistance between the heat sources and the measuring thermopile. Thus, the mount should be constructed of material with a high thermal conductivity and the thermal paths be short as possible. Typical commercial mounts are constructed of nickel-plated or gold-plated brass and might also have stainless steel parts in the thermal path.

The transfer standard should have a high effective efficiency. This means a low rf-loss input transmission line constructed of a high electrical conductivity material with a good surface finish.

To meet these requirements, the mount body is constructed of tellurium copper, while the parts of the mount that involve the input transmission line (the outer conductor) are made of electroformed copper. The electrical conductivity of copper is nearly 3 times better than brass and 30 times better than stainless steel. The thermal conductivity is about 2.5 times better than either brass or beryllium copper and 26 times better than stainless steel. The electroformed parts provide a better outer conductor surface than can be obtained by machining.

The disadvantage of these two materials is that they are softer than beryllium copper or brass. This is more of a liability for the Type N mount (because of a vulnerable connector outer conductor) than for the APC-7 design. With

careful handling, it is not a major problem with either design. Experience with one of the Type N mounts reveals no visible connector damage after more than 100 connections. All parts of the mount are gold plated to prevent deterioration of the surface characteristics, primarily thermal emissivity and electrical conductivity.

## 2.2 Mount Size

Valid measurements of the thermopile output and the power meter voltage cannot be made until the microcalorimeter and mount are in thermal equilibrium with the water bath, a condition indicated by a stable thermopile output. The time to reach stability may be lengthy: an average of 50 min per measurement frequency on the commercial mounts because of their long thermal time constant. A typical calibration at 105 points can take about 90 h. To minimize the effect of external temperature changes, all commercial mounts are typically massive and seek to thermally isolate the thermistor bead structures. Such design objectives are the opposite of those desired for use in the microcalorimeter. An effective way to speed the measurements is to minimize the thermal mass (heat capacity) of the bolometer mount by reducing the size and to eliminate the thermal isolation.

Both techniques are used in the new mounts. For example, the mass of the new Type N mount is approximately one-third that of the commercial version previously used (53 g versus 142 g). The average measurement time per frequency for the new design is less than 30 min (see Section 3).

## 2.3 Microwave Leakage

The rf leakage from the bolometer mount is a first-order source of error in the measurement. The leakage energy, because it is not dissipated in the mount, is not detected by the bolometer elements or by the microcalorimeter thermopile. Leakage may radiate or conduct through mechanical joints in the mount body, the dc bias leads, or the rf input connector. Commercial mounts, which are adequate for their intended use, generally do not have low enough leakage for this application, where errors on the order of 0.01 percent are of concern.

The effort to minimize leakage has focused on rf containment by the mount body and the dc bias circuit. The shielding is accomplished by totally enclosing the mount and minimizing any gap that might allow leakage at a mechanical joint. Residual leakage from threaded joints can be further reduced by painting the seam with conductive epoxy or paint. Because of the thin wall of the mount body, the cap is not threaded. It is designed to be a tight press fit in the body; in fact, a special fixture is needed to remove the cap. A puller tool is described in Appendix E. Once it is determined that a newly constructed mount is operating properly, the cap seam can also be sealed with conductive epoxy or paint.

The internal rf bypass structure consists of a tubular pi-section (a pair of capacitors with a ferrite inductor) low pass filter with an added external ferrite bead in each of four leads. A cross section of the dc feed-through structure is shown later in figures 4.1 and 4.2. The dc connection to the thermistor beads is through a miniature connector to allow the mount cap to be removed.



## 2.4 Thermistor Bead Assembly

As described earlier, the substitution type power meter measures power in terms of a change in the dc bias power. Uncertainty in the bolometer dc resistance will be reflected as an error in the power calculation. Lead or contact resistance in the dc bias circuit will generate such an error. The solution to this problem is a four-wire connection from the bolometer elements to a power meter which uses external sense leads such as the NIST Type IV power meter (made commercially by several manufacturers). The thermistor bead assembly used in the mount has the required four-wire connection.

Coaxial bolometer mounts typically use a dual bolometer configuration. The elements are connected in series for the dc bias and in parallel for the rf. This simplifies the dc bias connection and also provides a good rf match to the 50  $\Omega$  transmission line. However, if the electrical characteristics of the two elements are not identical, a dc-rf substitution error in the power measurement results. For thermistor mounts, the error increases in a nonlinear manner with rf power. The error is restricted to coaxial mounts, since in general, waveguide designs use a single element. The effect can be minimized by proper matching of the element pair. The beads in the assembly used are matched to 0.05  $\Omega$  at 165  $^{\circ}\text{C}$ . The details of the dual-element error are presented in reference [11].

Another performance parameter for the mount, which is a function of the bead assembly, is the input reflection coefficient. A low reflection coefficient is not necessary for the microcalorimeter measurement, but it is important for reducing the uncertainty in the calibration transfer and, as a practical matter, for reducing the minimum power requirement on the microwave source. The thermistor bead structure with its unique four-wire connection is a commercial product. This greatly simplifies the construction of the mount.

## 2.5 Effective Efficiency

As noted in Section 2.1, the effective efficiency should be high, at least above 90 percent. Another desirable feature is that  $\eta_e$  be a slow, smoothly varying function of frequency. Most thermistor mounts display resonances, or sharp narrow dips in  $\eta_e$ . Because  $\eta_e$  is changing very rapidly with frequency at these points, the random uncertainty is greater, and interpolation between measured points is not possible. As will be described in Section 3.5, the resonances can be suppressed. Figure 2.1 is a plot of effective efficiency versus frequency for the same mount shown in figure 1.3, but without resonance suppression.



Figure 2.1. Type N mount effective efficiency before resonance suppression.

### 3. PERFORMANCE

Material presented in this section reports the actual measured performance of several samples of the Type N mount only. (At the time of this publication, customer interest in an APC-7 service has not been sufficient to warrant constructing the mounts or evaluating the calorimeter. The parts, however, are in hand and can be assembled and evaluated if needed in the future.) These measurements are thought to be typical and thus representative of future units. The basis of these performance measures was presented earlier in Section 2.

#### 3.1 Microwave Leakage

Detection of microwave leakage is relatively easy; accurate measurement of its magnitude is not. Development of special techniques and facilities such as the reverberation chamber and the TEM cell make such measurements potentially possible [12]. A reverberation chamber can be used to measure the energy above about 300 MHz (the low frequency limit is determined by the size of the available chamber) that is radiated from the mount and its connected dc bias cable. Energy that is conducted from the mount on the connecting dc bias cable can be measured using a vector voltmeter and a spectrum analyzer. Measurements on early prototype mounts show that most of the energy escaping from the mount is conducted away on the connecting cable, rather than being radiated. Therefore, measurements were not made in the reverberation chamber.

Results shown in figure 3.1 were obtained from measurements on the mount using a vector voltmeter at the low frequencies and a spectrum analyzer above 1 GHz. The objective was to keep total leakage from the mount more than 40 dB below the input (less than 0.01 percent of the input). The figure indicates this was achieved.

#### 3.2 Input Reflection Coefficient

As previously indicated, it is desirable for the magnitude of the input reflection coefficient to be small. The measurements made by an automatic vector network analyzer (45 MHz to 18 GHz) and by a six-port network analyzer (10 MHz to 50 MHz) on a typical Type N mount are shown in figure 3.2. The magnitude is under 0.1 from about 20 MHz to 16.5 GHz.

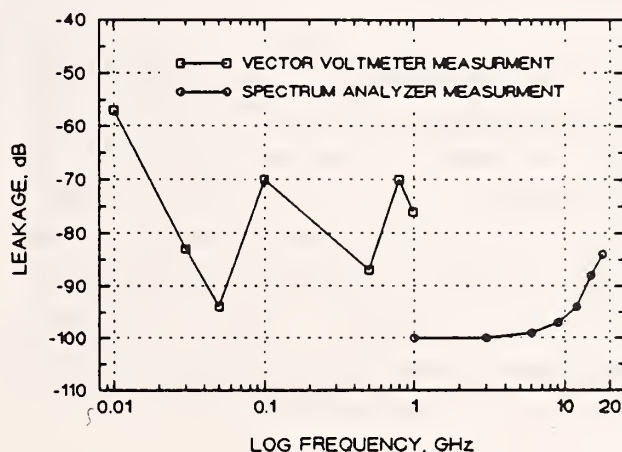


Figure 3.1. Microwave leakage in decibels below the input.

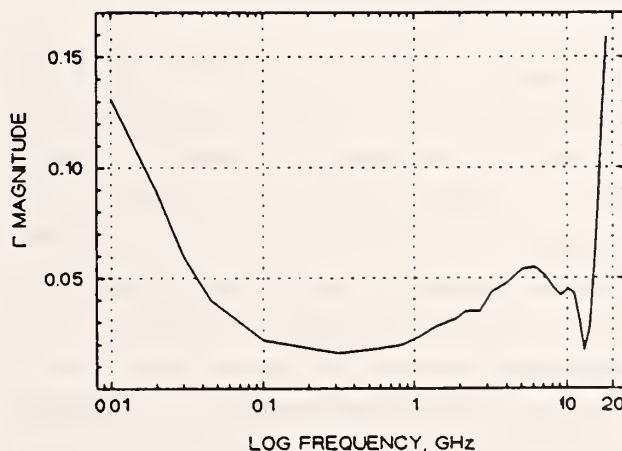


Figure 3.2. Type N mount reflection coefficient.



### 3.3 Dual Element Error

First, if the mount is used at 10 mW, where it was calibrated, there is no error. However, if the mount is used as a reference standard to calibrate another system at a different power, say 1 mW, then there may well be an additional uncertainty in the measurement.

The only way to determine the magnitude of the dual-element error is by direct measurement. In theory, one possible measurement method is to connect the coaxial mount to one arm of a nominally equal power splitter (such as a 3 dB hybrid or a waveguide "magic tee") and a single element waveguide mount to the other arm. The ratio of the two bolometric powers is determined at 10 mW and again at a randomly selected power between 10 mW and 0.1 mW. The change in the ratios as determined at the two powers is a measure of the dual-element error. The process is repeated enough times to give a curve showing the nonlinearity as a function of power up to 10 mW.

The test of the procedure is to place identical model waveguide mounts on each arm of the power splitter to verify the linearity of the splitter and associated instrumentation. Figure 3.3 shows results of such a measurement with two identical model waveguide mounts at 9.1 GHz. The increased spread of the data as the power decreases is typical of bolometric measurements because of the small change in dc power that occurs at low microwave power.

The result for a commercial coaxial mount compared with one of the waveguide mounts is shown in figure 3.4. The error is very small at low power and increases to about 0.035 percent at 10 mW.

Unfortunately, most of the data taken using this technique does not give results comparable to figures 3.3 and 3.4. Considerable time has been put into the effort to reduce this approach to a reliable measurement technique. Thus far, it has not been successful. Generally, the results of the power splitter linearity tests have not provided the desired verification, so the comparisons between the coaxial mount and a waveguide mount are not meaningful. The difficulty seems to be that when looking for deviations on the order of 0.01 percent, instrumentation problems such as the inability to locate the ground precisely where it

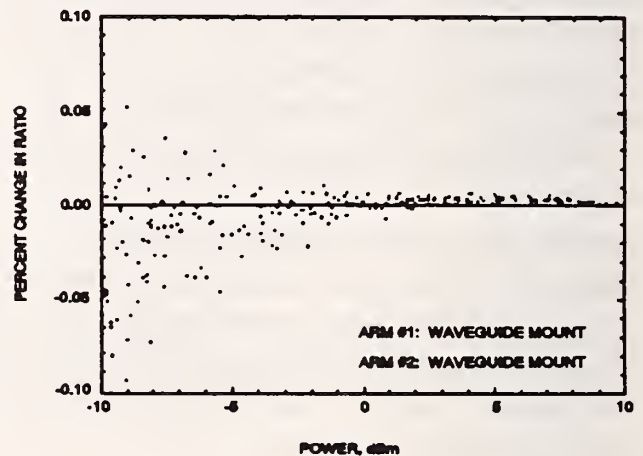


Figure 3.3. Change in the power ratio of two waveguide mounts versus power.

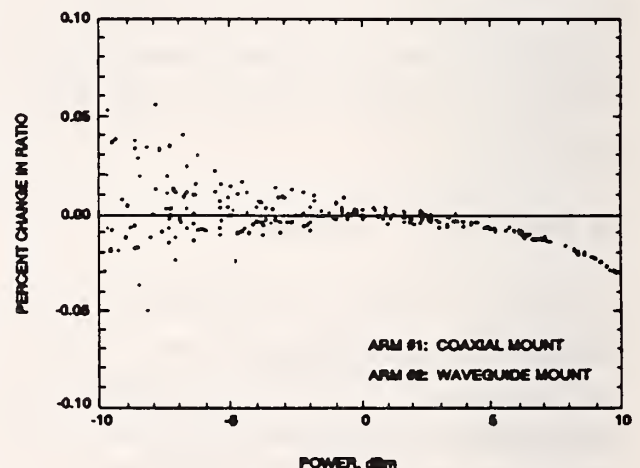


Figure 3.4. Change in the power ratio of a coaxial mount to a waveguide mount versus power.

should be in the dc measurement circuit or the effect of stray thermal junctions are of the same order. At best, the comparison between the coaxial and waveguide mounts is in error by the amount of the apparent nonlinearity seen when comparing a waveguide mount to a waveguide mount.

Another way to determine the dual-element error is to measure the effective efficiency as a function of power. Figure 3.5 shows that measurement on a Type N mount. The significant nonlinearity above about 12 mW is largely due to the dual-element error. At the lower power levels the measurement uncertainty becomes quite large so the shape of the curve is not necessarily accurate. A line fitted to the measured data between 5 mW and 12 mW is shown in figure 3.6. Based on this linear fit, the change in efficiency between 10 mW and 1 mW is less than 0.01 percent. This is a better estimate of the dual-element error than the power splitter method provides.

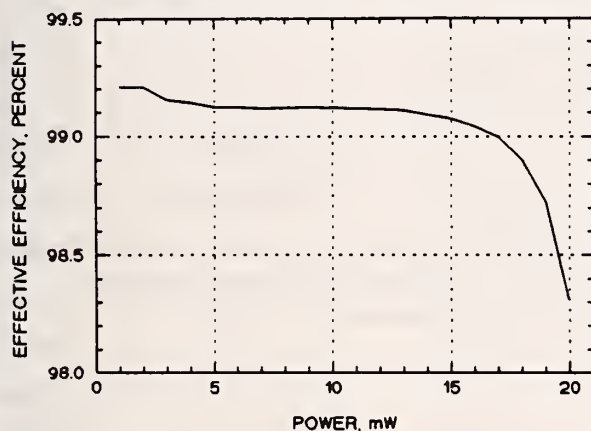


Figure 3.5. Effective efficiency as a function of power.

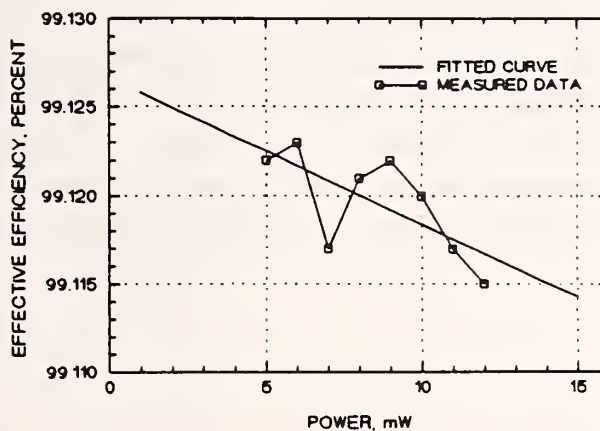


Figure 3.6. Linear fit to data of figure 3.5 from 5 to 12 mW.

### 3.4 Mount Settling Time

In figure 3.7, the upper trace is the output of a crystal detector monitoring a 10 GHz source as the rf is turned on for about 6 ms, and then turned off. The lower trace is the power meter voltage of the coaxial thermistor mount as it measures the same output. Note the rather large "overshoot" excursions that occur for about 2 ms until a steady state is reached. These excursions may occur because the current distribution in the thermistor beads changes when rf is applied, so the heat distribution must also change. It takes a few milliseconds for a new thermal steady state to be reached. Thus the measurement of the power meter voltages should not be made until after the overshoot

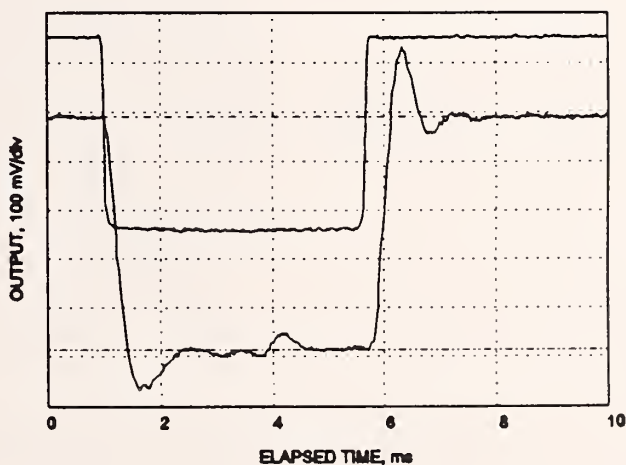


Figure 3.7. Crystal detector and mount output as rf power is switched on and off. The source output is 10 mW.

has subsided. The effect decreases with decreasing power and is independent of frequency.

### 3.5 Effective Efficiency

A plot of the effective efficiency of one of the Type N mounts was shown in figure 1.3. The efficiency is well above 90 percent and decreases smoothly with frequency. Figure 3.8 is a plot of the  $\eta_e$  of a mount before and after suppression of the resonant behavior described in Section 2.5. The resonance effect is the result of microwave leakage past the thermistor beads into the space that forms a cavity behind the thermistor bulkhead. The effect can be reduced or even eliminated by filling the cavity with two layers of magnetic microwave absorber. The fill material is fastened in place to prevent movement which could change the  $\eta_e$ .

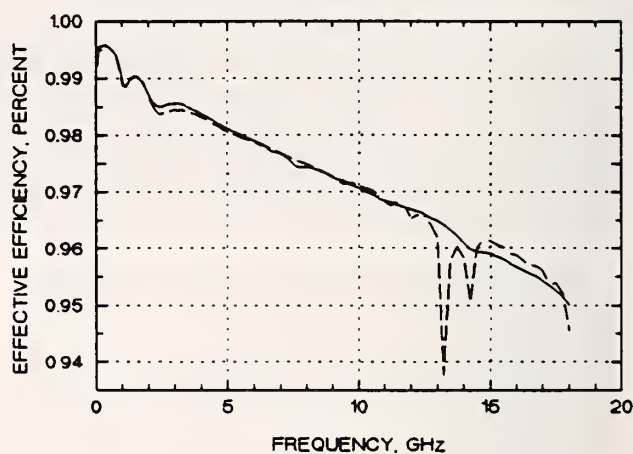


Figure 3.8. Type N mount effective efficiency before (dashed line) and after resonance suppression.

## 4. FABRICATION and ASSEMBLY

### 4.1 Mechanical Design and Drawing Reference

Figure 4.1 shows a cross section of the Type N mount with the parts identified. Figure 4.3 and 4.4A are exploded cross sectional views that give an ID designator for each part. The parts are listed in tables in appendix A. The items that can be obtained commercially are listed in table A.1. The supply sources for these parts are listed in table A.2. Table A.3 contains the parts that must be fabricated. The first letter of the figure number indicates in which appendix the dimensioned part drawing can be found. Included in appendix B is figure B6, the wiring convention for the dc bias connector J1.

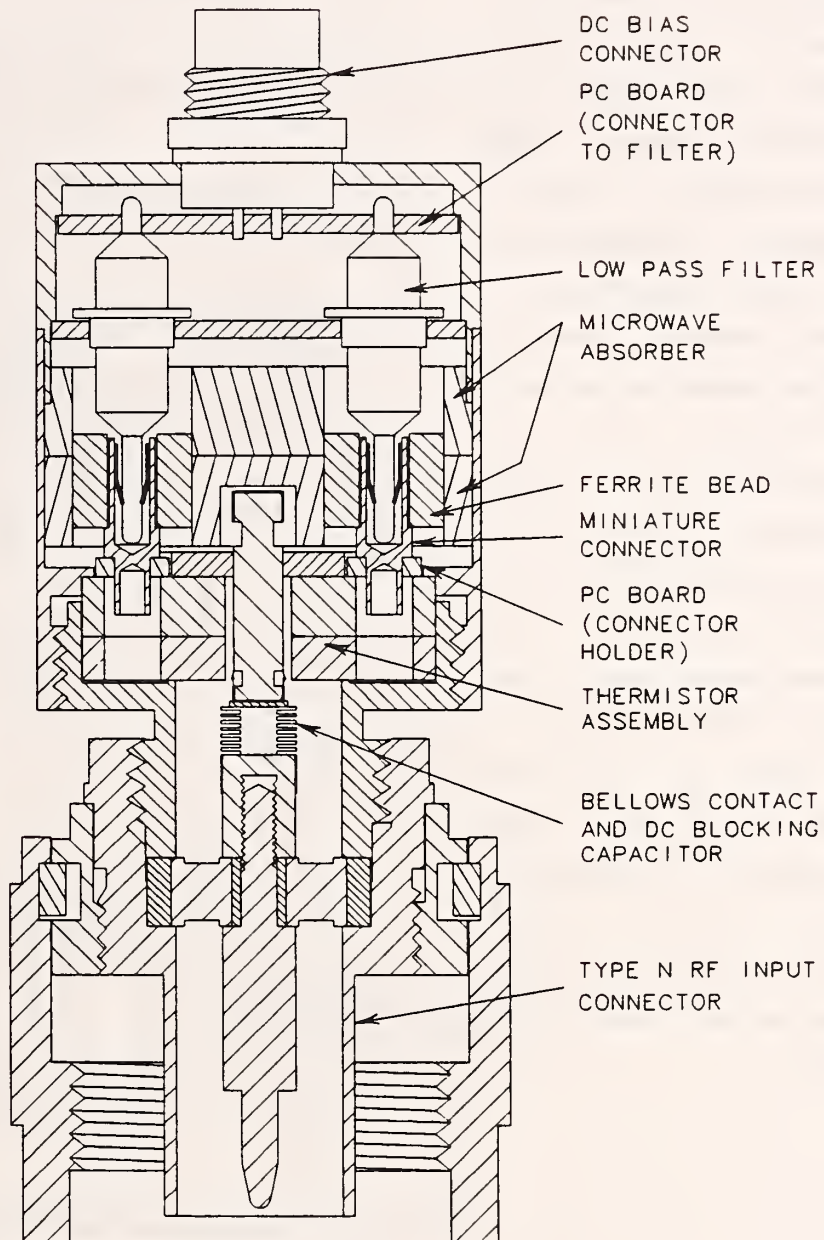


Figure 4.1. Cross section of the Type N thermistor mount.



Figure 4.2 shows a cross section of the APC-7 mount with the parts identified. Figure 4.3 and 4.4B are exploded cross sectional views that give an ID designator for each part. The parts are listed in tables in appendix A. The items that can be obtained commercially are listed in table A.1. The supply sources for these parts are listed in table A.2. Table A.3 contains the parts that must be fabricated. The first letter of the figure number indicates in which appendix the dimensioned part drawing can be found. Included in Appendix B is figure B6, the wiring convention for the dc bias connector J1. Note that part D2 may be supplied with part APC1. However, it cannot be used because it is not made of copper.

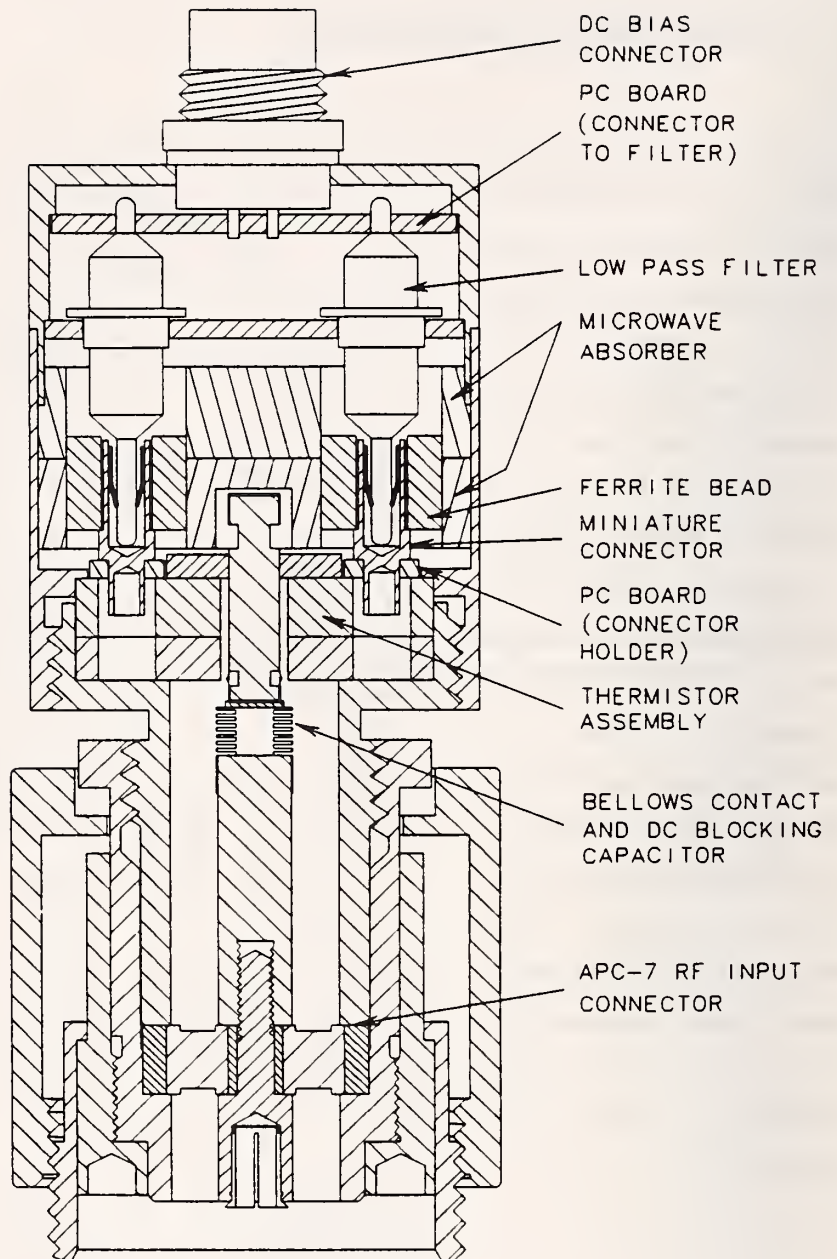


Figure 4.2. Cross section of the APC-7 thermistor mount.



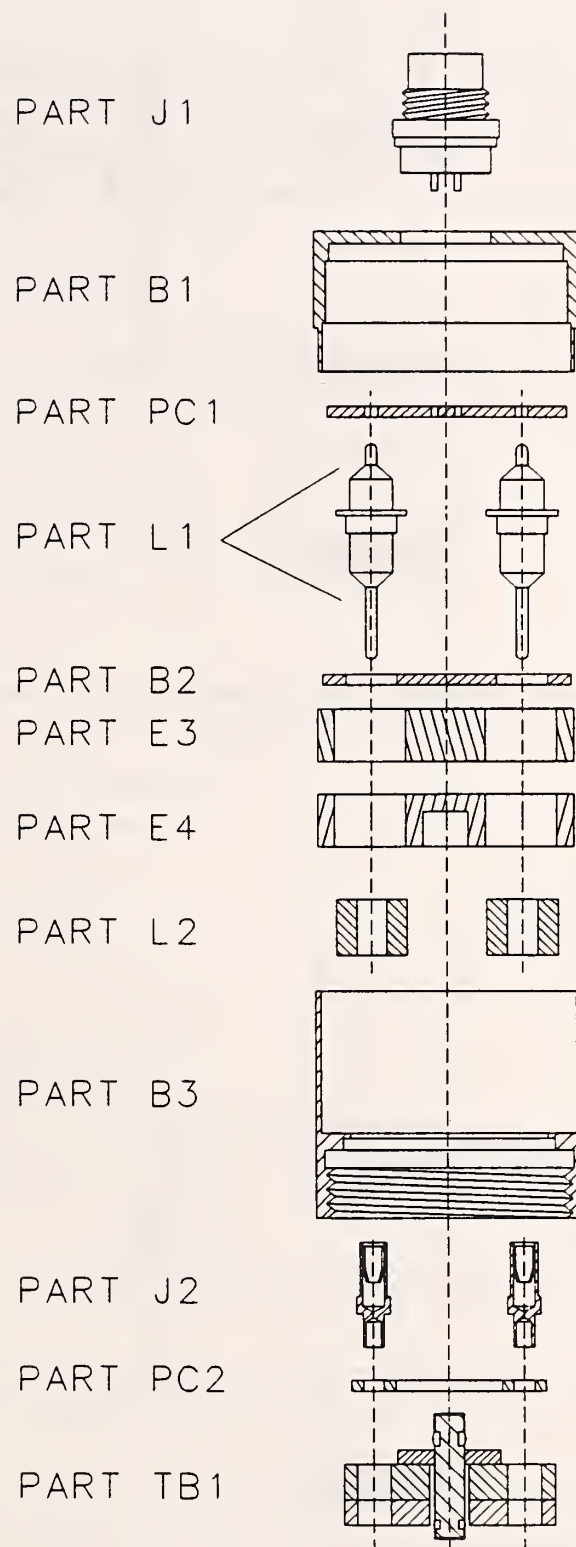


Figure 4.3. Drawing and part reference for the parts common to both the Type N and the APC-7 thermistor mount.

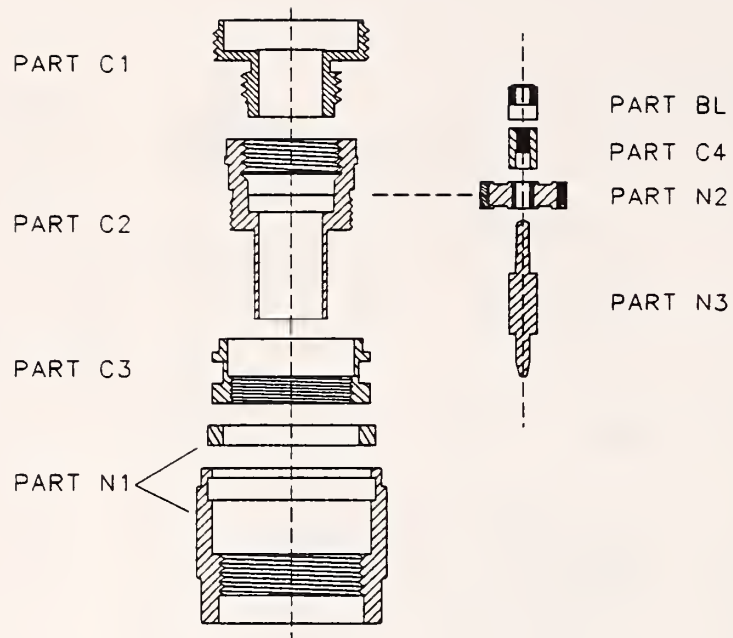


Figure 4.4A. Drawing and part reference for the parts specific to the Type N thermistor mount.

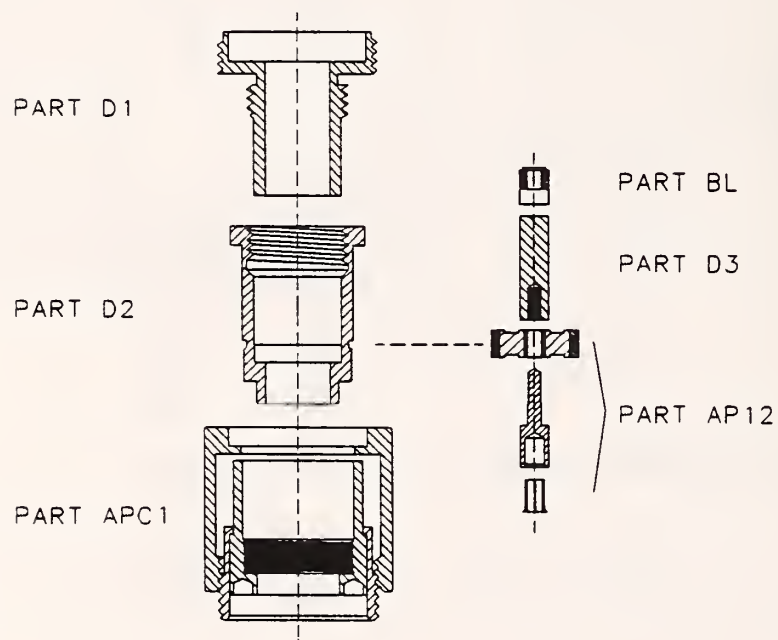


Figure 4.4B. Drawing and part reference for the parts specific to the APC-7 thermistor mount.

## 4.2 Assembly Details

The following section describes detailed steps for the assembly of the Type N coax mount. The APC-7 version is not described separately because its assembly would differ only in minor ways with respect to the connector. The items in parenthesis are part designations. Assembly of the mount is done in 4 stages. These stages are cap, body, connector, and final mount assembly. Each stage is made up of several steps.

### 4.2.1 End Cap Assembly Instructions

The first stage of construction is to assemble the end cap. Refer to appendix A and figure 4.5 during this stage of construction. The tools, supplies, and parts needed are listed below, followed by the assembly steps.

1. Soldering iron and associated tools
2. Solder, No. 24 S.W.G. 63 % Sn/37 % Pb
3. Trichloroethane technical
4. Ultrasonic cleaner
5. Deionized water
6. Hot plate
7. Conductive silver paint (S5)
8. Four-conductor miniature connector (J1)
9. Low pass filter (L1), four each
10. Pc board (PC1)
11. Low pass filter plate (B2)
12. End Cap (B1)

Step 1. Attach miniature connector to end cap.

- a. Heat hot plate to 232°C (450°F).
- b. Remove rubber gasket from the miniature connector (J1).
- c. Wrap one loop of solder around the base of the miniature connector.
- d. Push the connector into the end cap (B1).
- e. Place the end cap on the heated hot plate.
- f. After solder flows remove end cap from the hot plate and allow to cool.

Step 2. Solder four low pass filters (L1) to each of the outer diameter holes on the pc board (PC1). Place each filter so that the flange is facing away from the pc board.

Step 3. Insert the pc board with attached filters into the end cap, aligning the center holes on the pc board with the four conductors of the miniature connector. The pc board should rest on the inside lower lip of the end cap.

Step 4. Solder miniature connector leads to pc board.

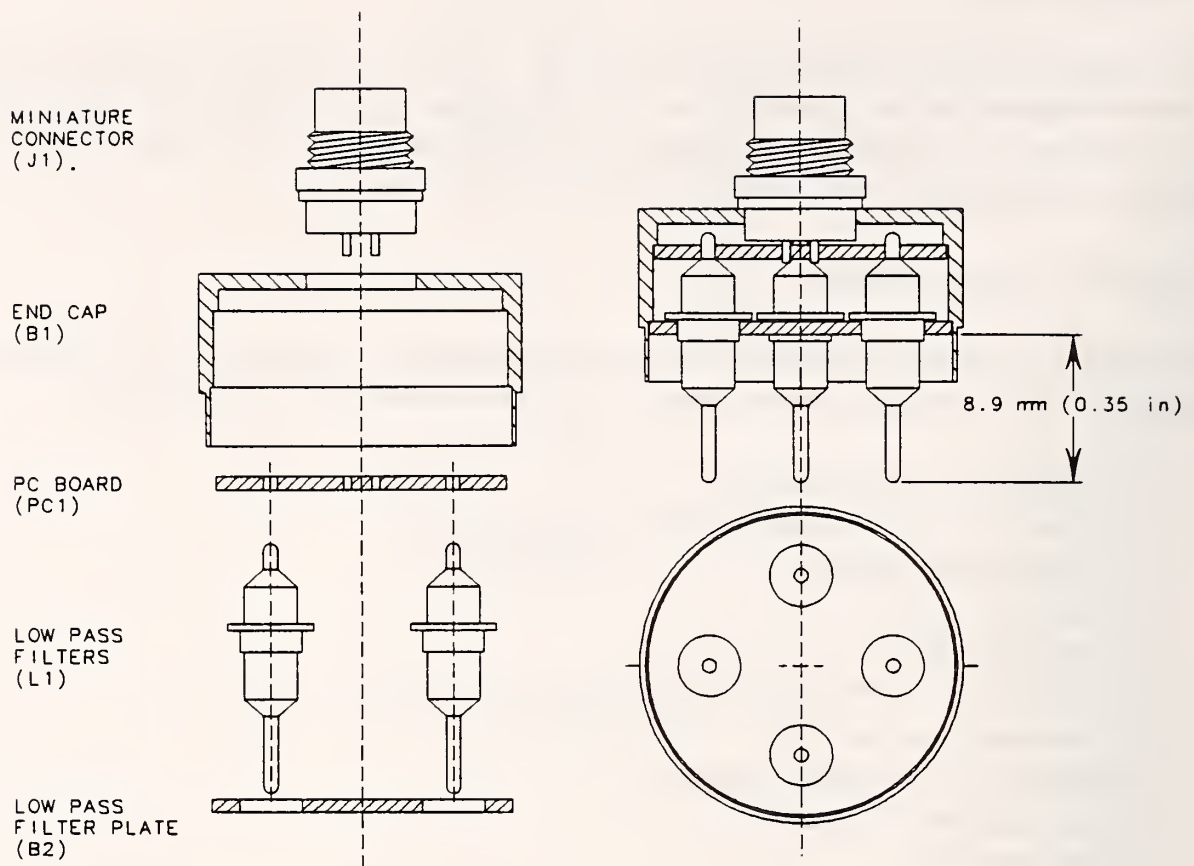


Figure 4.5. End cap assembly.

Step 5. Clean the inside of the end cap of all flux residue and deposits.

- a. Soak the end cap in a trichloroethane ultrasonic bath for at least 15 min.
- b. Rinse the end cap in deionized water and allow to air dry.

Step 6. Push filter plate (B2) into end cap until plate rests on the inside upper lip of the end cap.

Step 7. Trim the filter leads to 8.9 mm (0.35 in) from filter plate.

Step 8. Attach and seal filter plate to end cap and filters with conductive silver paint (S5).

#### 4.2.2 Body Assembly Instructions

The second stage of construction is the assembly of the mount body. Refer to Appendix A and figures 4.6 and 4.7 during this stage of construction. The list of tools, supplies, and parts needed are followed by the assembly steps.

1. Soldering iron and associated tools
2. Wrench C, see figure E1 in Appendix E
3. Solder, No. 24 S.W.G. 63% Sn/37% Pb

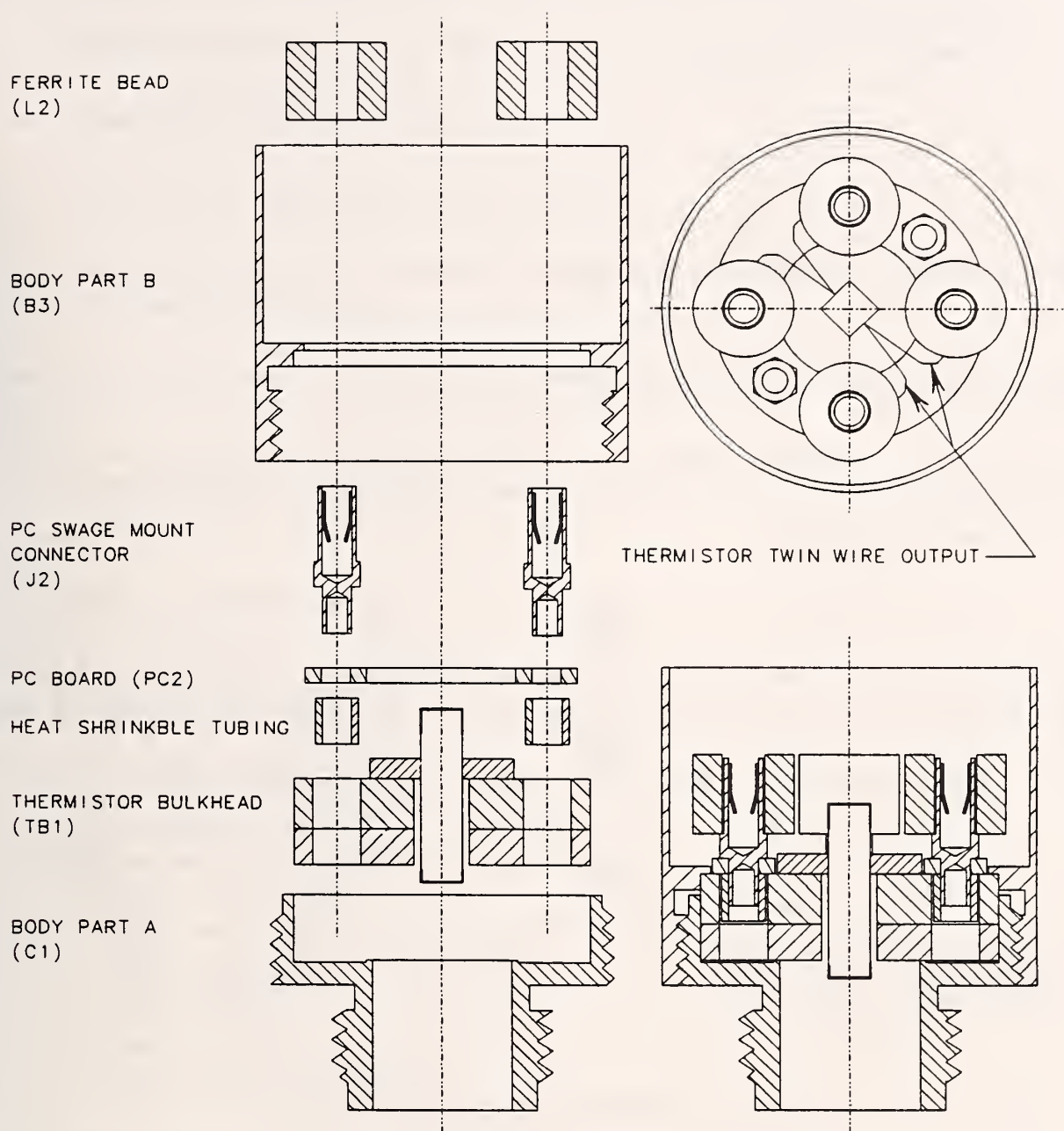


Figure 4.6. Mount body assembly.

4. Ferrite shielding bead (L2), four each
5. Pc swage mount connector (J2), four each
6. Thermistor bulkhead (TB1)
7. Thermally conductive epoxy (S4)
8. Heat shrinkable tubing, 3/64 in diameter
9. Body part A (C1)
10. Body part B (B3)



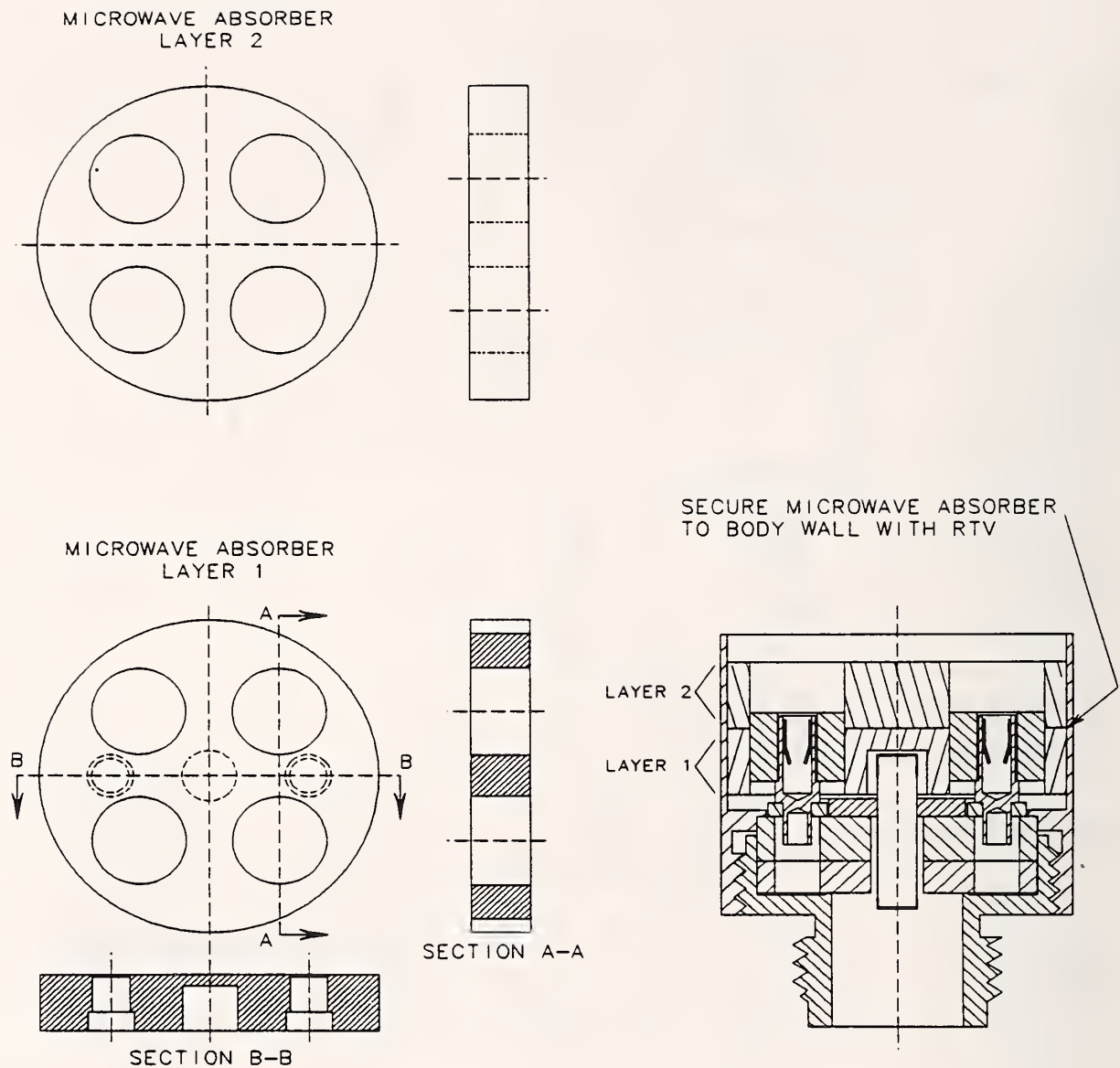


Figure 4.7. Molded RTV magnetic absorber parts.

11. Pc board (PC2)
12. Microwave absorbers (E3 and E4; for instructions to make them, see Appendix E)
13. Silicone rubber coating (S1)

Step 1. Solder four pc swage mount connectors (J2) to pc board (PC2).

Step 2. Cover protruding connector ends on under side of PC board with heat shrinkable tubing.

Step 3. Place the pc board with attached connectors on the thermistor bulkhead (TB1), aligning the pc board with the two threaded studs.

- Step 4. Using two # 0-80 nuts, secure the pc board to the thermistor bulkhead studs.
- Step 5. Solder each thermistor lead wire to the bottom of its corresponding connector; see figure 4.6.
- Step 6. Place thermistor bulkhead in body part A (C1).
- Step 7. Using wrench C tighten body part B (B3) to body part A.
- Step 8. Inspect the assembly under a microscope to see that the thermistor bulkhead is seated tightly against the outer conductor of body part A.
- Step 9. Attach a ferrite bead (L2) with thermally conductive epoxy to each of the pc swage mount connectors.
- Step 10. Place two microwave absorbers into mount body as shown in figure 4.7. Secure each of the absorbers to the mount body wall with a small amount of RTV (S1). Let RTV cure for 24 h before final assembly.

#### 4.2.3 Connector Assembly Instructions

The third stage of construction is the assembly of the connector. Refer to Appendix A and figure 4.8 during this stage of construction. The tools, supplies, and parts needed are listed below, followed by the assembly steps.

1. Two collets, both sized to hold the 3.040 mm (0.1197 in) center conductor, with holders (3.1 mm type D is suggested)
2. Wrenches A and B, see figure E1 in Appendix E
3. Type N male pin (N3)
4. Type N center conductor support bead (N2)
5. Type N conductor shell and coupling ring (N1)
6. Connector body (C2)
7. Coupling nut (C3)
8. Center conductor extension (C4)

- Step 1. Insert the threaded end of the Type N male pin (N3) through the center of the center conductor support bead (N2).
- Step 2. Attach the center conductor extension (C4) to the threaded end of the Type N male pin. Orientate the center conductor extension so that the thread relief is towards the center conductor support bead. Apply sufficient torque to insure that the thread will not loosen by using the collets, either manually or in a lathe. Exercise care to not mar the center conductor surface or strip the threads.
- Step 3. Place the pin with support bead and extension into the connector body (C2) making sure the support bead is properly seated.

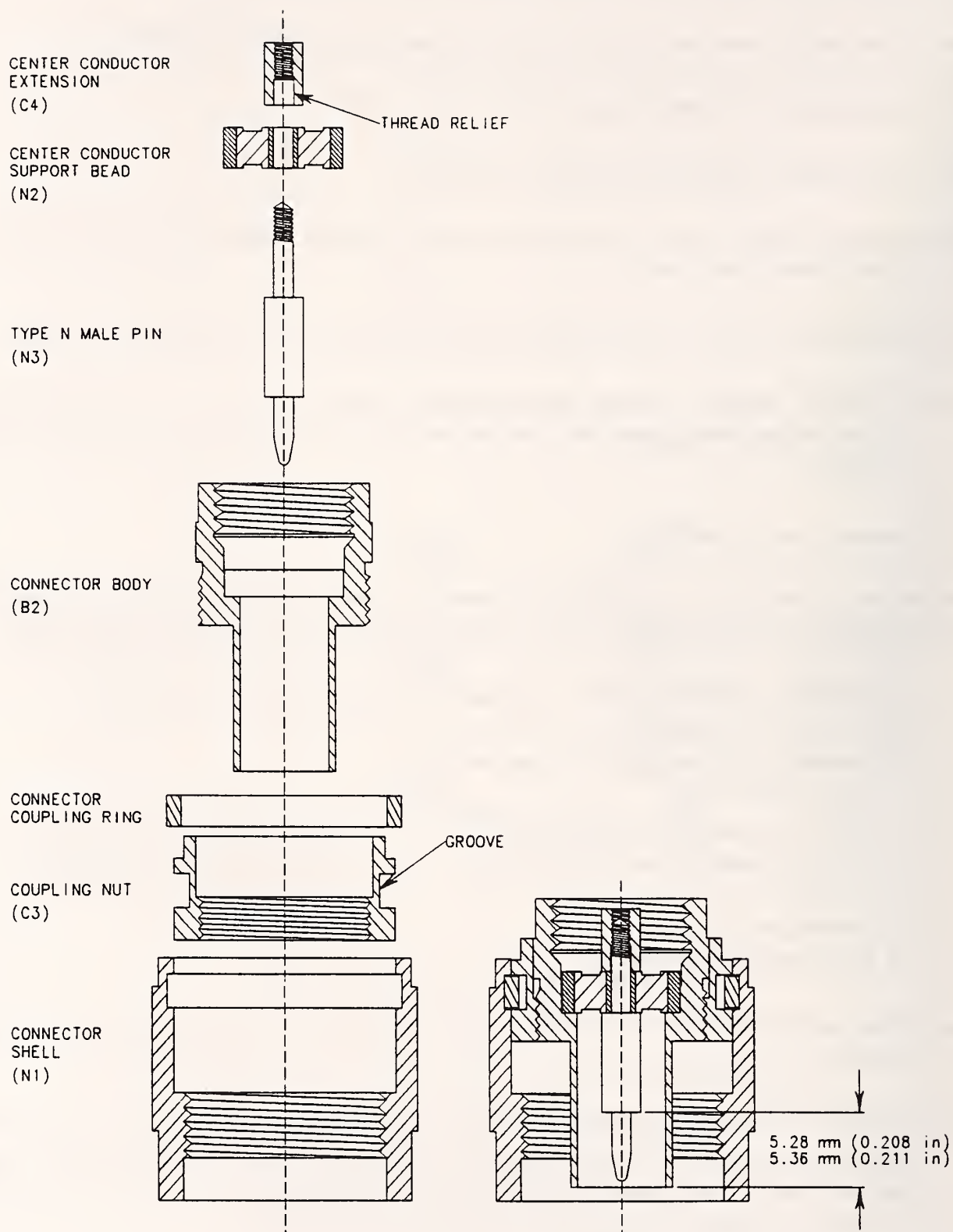


Figure 4.8. Connector assembly.

Step 4. Slip the connector coupling ring (N1) onto the coupling nut (C3) so that it rests in the coupling nut groove.

Step 5. Thread the connector (C2) body into the coupling nut.

Step 6. Push the connector shell (N1) over the coupling nut and ring assembly.

Step 7. Using wrenches A and B tighten assembly.

#### **4.2.4 Mount Assembly Instructions**

The final stage of construction is the assembly of the mount utilizing the cap, body, and connector assemblies. Refer to Appendix A and figure 4.9 during this stage of construction. The tools, supplies, and parts needed are listed below, followed by the assembly steps.

1. Cap assembly
2. Body assembly
3. Connector assembly
4. Bellows contact and dc blocking capacitor (BL)
5. Wrenches B and C, see figure E1 in Appendix E
6. Mount assembly tool, see figure E2 in Appendix E

Step 1. Place bellows on connector assembly center conductor extension.

Step 2. Tighten body to connector assembly using wrenches B and C; make sure to keep the bellows properly seated.

Step 3. Press the cap into the body assembly using the mount assembly tool (figure E2), keeping the notch on the miniature connector aligned with either one of the shorted internal connector pair as indicated in figure 4.9. Use an ohmmeter to identify the shorted pair.

Step 4. Check the Type N connector dimensions; the measurements should be between 5.28 mm (0.208 in) and 5.36 mm (0.211 in). See detail in figure 4.8.

#### **4.2.5 Mount Operating Instructions**

A copy of the mount operating manual is found in Appendix F. The Type N version of the mount has been designated a Model CN and is so identified in the operating manual.



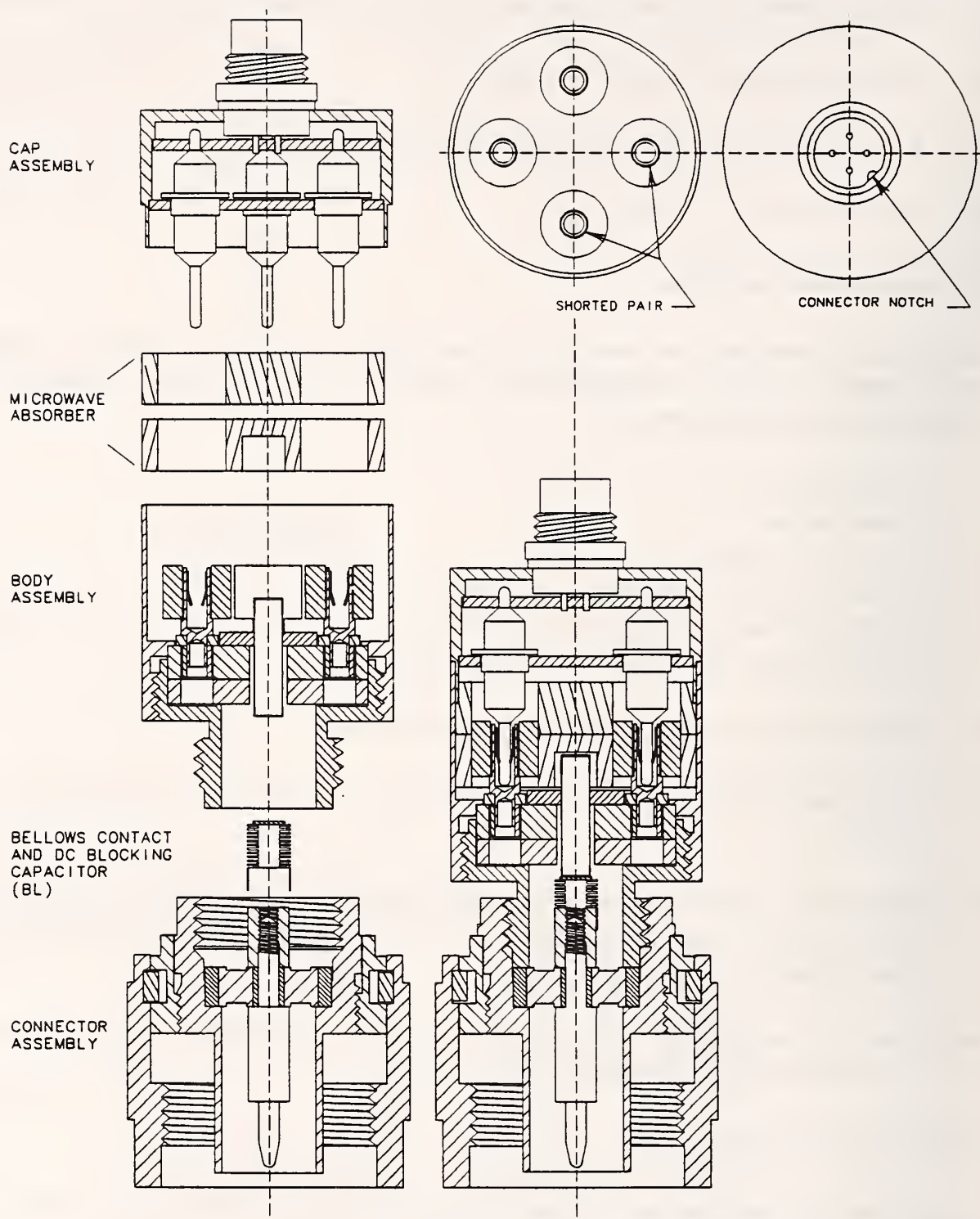


Figure 4.9. Final mount assembly.



## 5. ACKNOWLEDGEMENTS

The authors acknowledge the helpfulness of the early work and ideas of Morris E. Harvey upon which this effort is based. Thanks also to Neil T. Larsen for his support and many helpful discussions and suggestions. This work was partially funded by the Calibration Coordination Group of the Department of Defense.

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## APPENDIX A. Parts List

These tables identify the parts and supplies that can be obtained commercially and those parts that must be fabricated.

Table A.1. Commercial parts list			
Part ID	Description	No./mount	Part No, Manufacturer
APC1	7 mm connector assembly	1	No. 131-91051, 7 mm connector for air line Amphenol Connector Division
BL	DC blocking capacitor with bellows	1	No. 08478-60015, blocking capacitor Hewlett-Packard Company
J1	4-conductor miniature connector	1	No. DR-4S-4PC, printed circuit receptacle (mating connector: DP-4S-1 straight plug) Microtech, Inc. Boothwyn, PA 19061, (215) 459-3566
J2	Single-conductor miniature connector	4	No. MC72, pc swage mount SPC Technology (Newark catalog No. 46N7630)
L1	Low pass filter	4	No. 1234-0000, pi section solder mount single muRata/Erie North America, Inc. (Newark catalog No. 90F2245)
L2	Ferrite bead	4	No. 52004-4S2, shielding bead Ferroxcube, Phillips Components, Discrete Products Div.
N1	Type N connector coupling ring	1	No. 8812S2, snap ring No. 8812S1, coupling nut Maury Microwave Corp. Ontario, CA 91746, (714) 987-4715
N2	Type N center conductor support bead	1	No. 5040-0306, insulator, rf connector Hewlett-Packard Co.
N3	Type N male pin	1	No. 1250-0917, rf contact Hewlett-Packard Co.
TB1	Thermistor bulkhead	1	Model 8478B option K01, thermistor bulkhead Hewlett-Packard Co.

Table A.2. Supplies list		
Supply ID	Description	Part No, Manufacturer
S1	Silicon rubber	3140 RTV Coating, Dow Corning
S2	Low viscosity silicon rubber	RTV 615A, Silicone Rubber Compound GE Silicones, General Electric Co., Waterford, NY 12188 (518) 237-3330
S3	Carbonyl iron powder	Micropowder Iron, Grade S-5641 (carbonyl iron) International Specialty Products, 1361 Alps Rd., Wayne, NJ 07470, (800) 622-4423
S4	Thermally conductive epoxy adhesive (electrically insulating)	Thermalbond 4952 Thermalloy, Inc, PO Box 810839, Dallas, TX 75381-0839 (214) 243-4321

Table A.2. Supplies list (continued)

S5	Conductive silver paint	Type 22-202, GC Electronics (Newark catalog No. 00Z869)
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Table A.3. Fabricated parts list

Part ID	Description	No./ mount	Figure number
B1	End cap	1	B1
B2	Low pass filter plate	1	B2
B3	Body part B	1	B3
PC1	Connector/filter printed circuit board	1	B4
PC2	Thermistor bulkhead printed circuit board	1	B5
C1	Body part A (Type N)	1	C1
C2	Connector body (Type N)	1	C2
C3	Coupling nut mounting ring (Type N)	1	C3
C4	Center conductor extension (Type N)	1	C4
D1	Body part A (APC-7)	1	D1
D2	Connector body (APC-7)	1	D2
D3	Center conductor extension (APC-7)	1	D3
E1	Special assembly wrench A, B and C	-	E1
E2	Mount cap puller	-	E2
E3	Microwave absorber	1	E3
E4	Microwave absorber	1	E3

The material, plating, and other items specified on the drawing must be strictly complied with in the fabrication of the part. The mount cannot be used as a transfer standard that is calibrated directly in the microcalorimeter if they are not. The evaluation and error analysis of the microcalorimeter are not valid unless the mount to be used as the transfer standard is made exactly to the NIST design as specified by the drawings.

# APPENDIX B. Part Drawings Common to Both Mounts

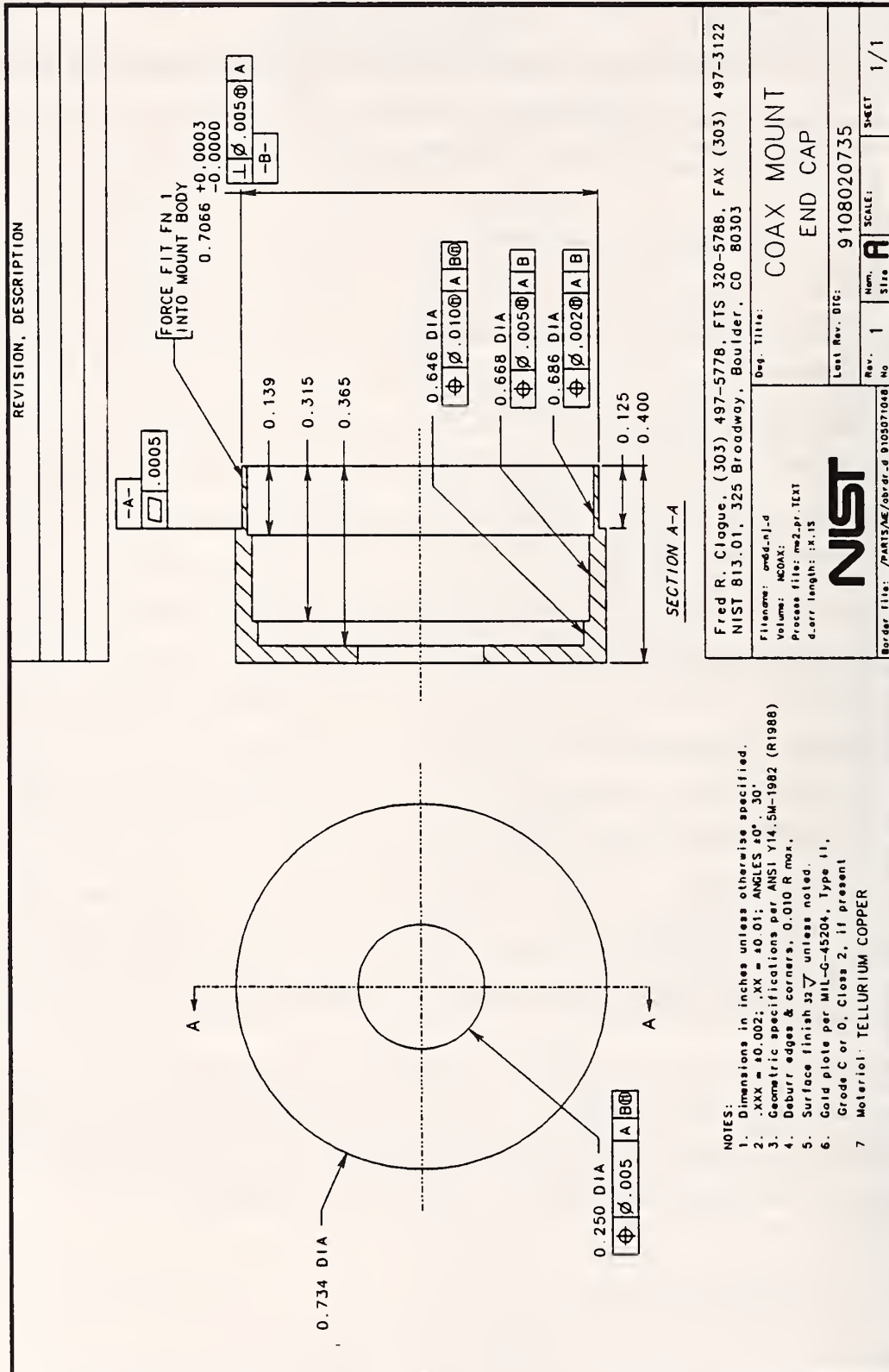


Figure B1. End cap, part B1.



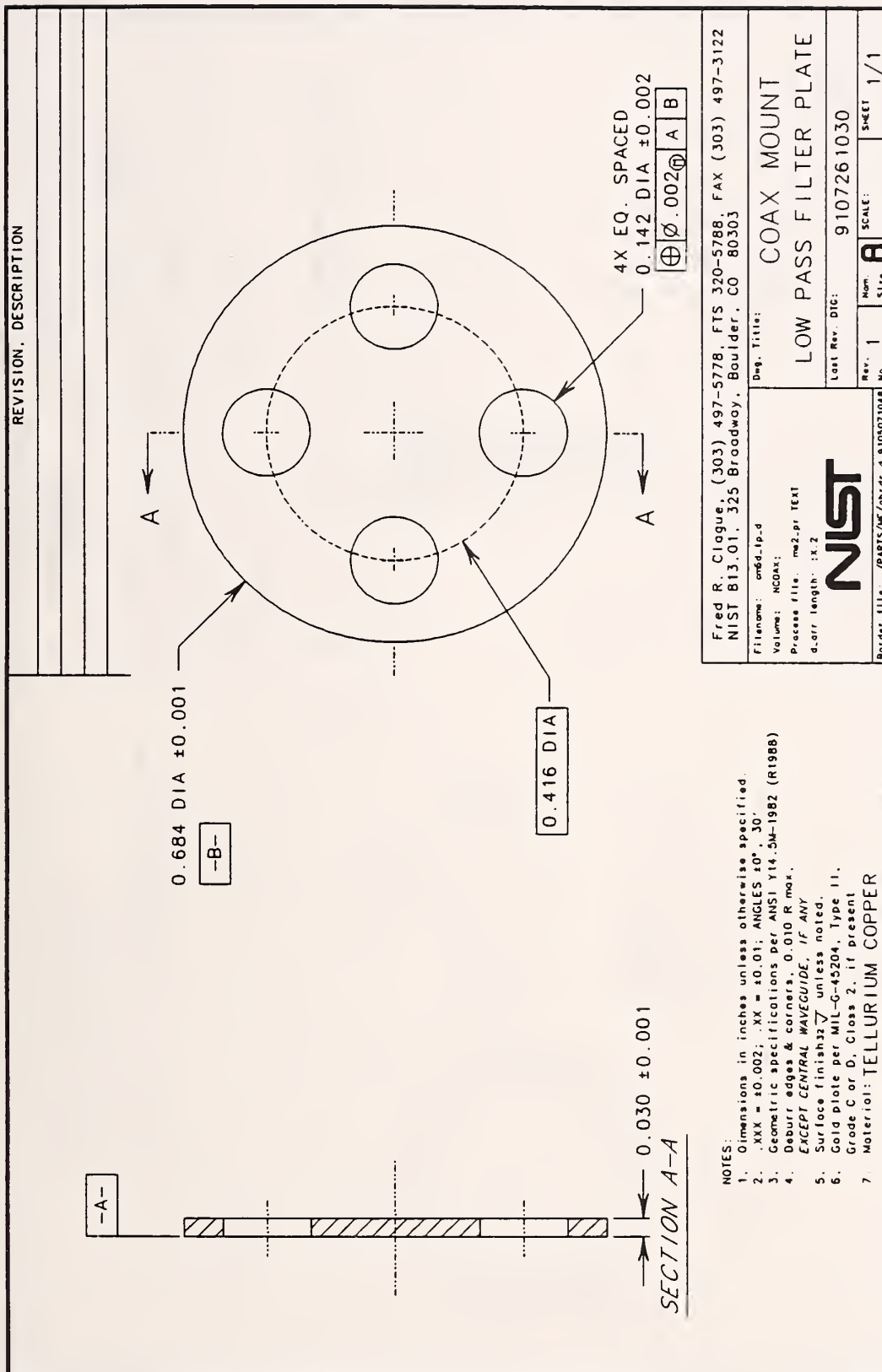


Figure B2. Low pass filter plate, part B2.

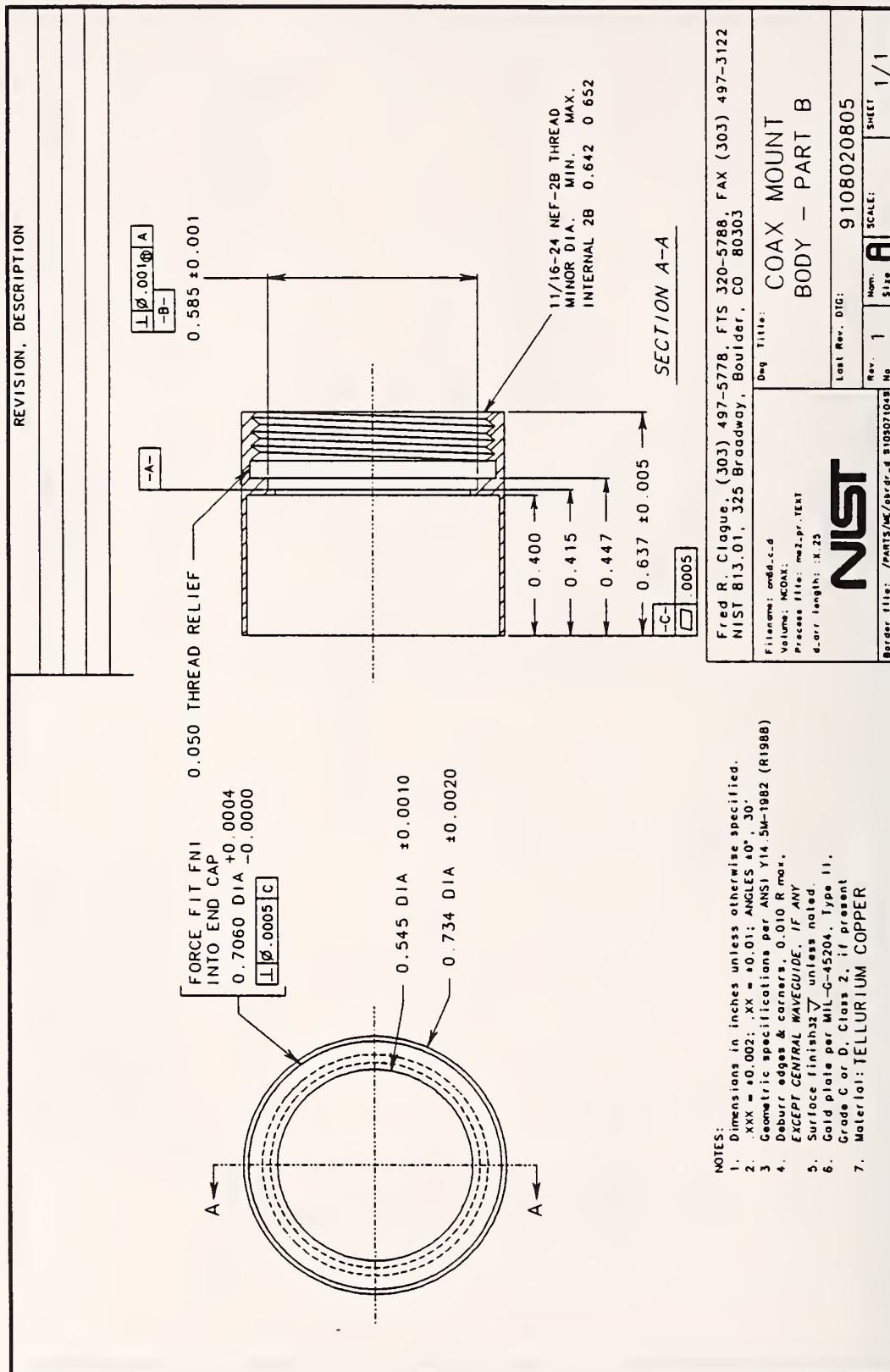


Figure B3. Mount body, part B3.

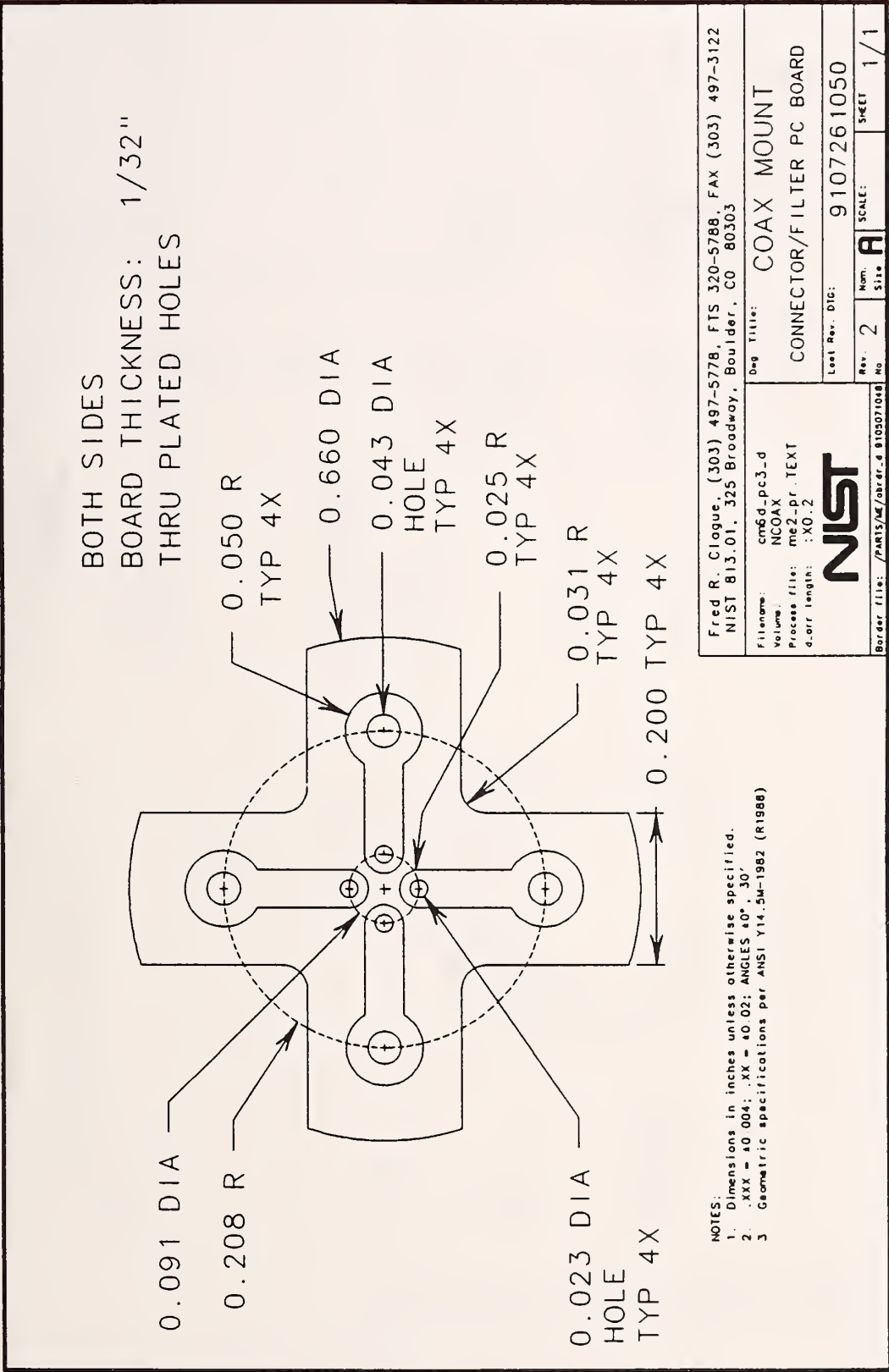


Figure B4. Printed circuit board, part PC1.

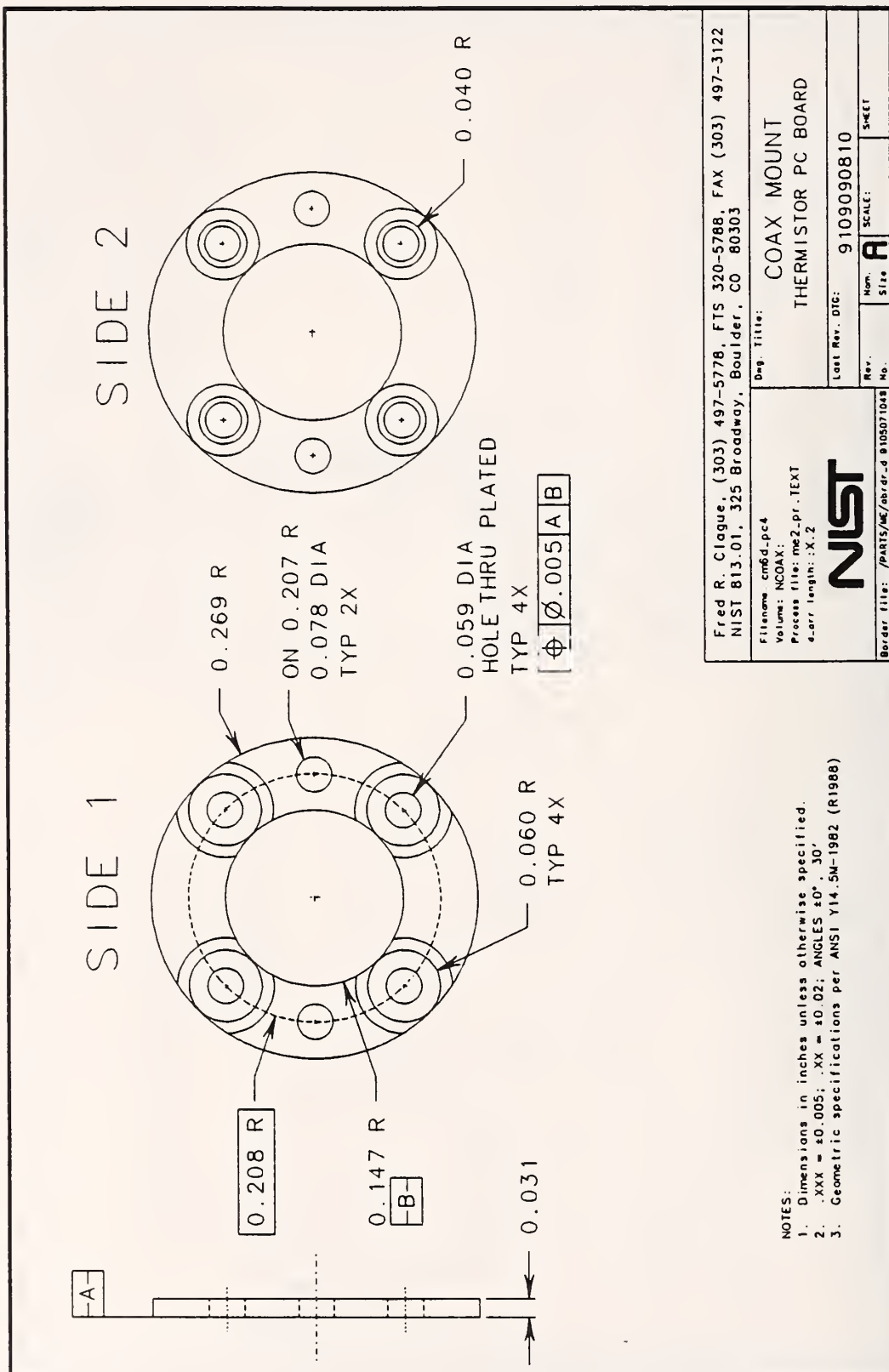
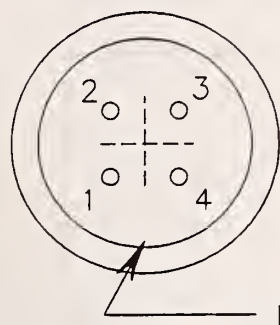


Figure B5. Printed circuit board, part PC2.



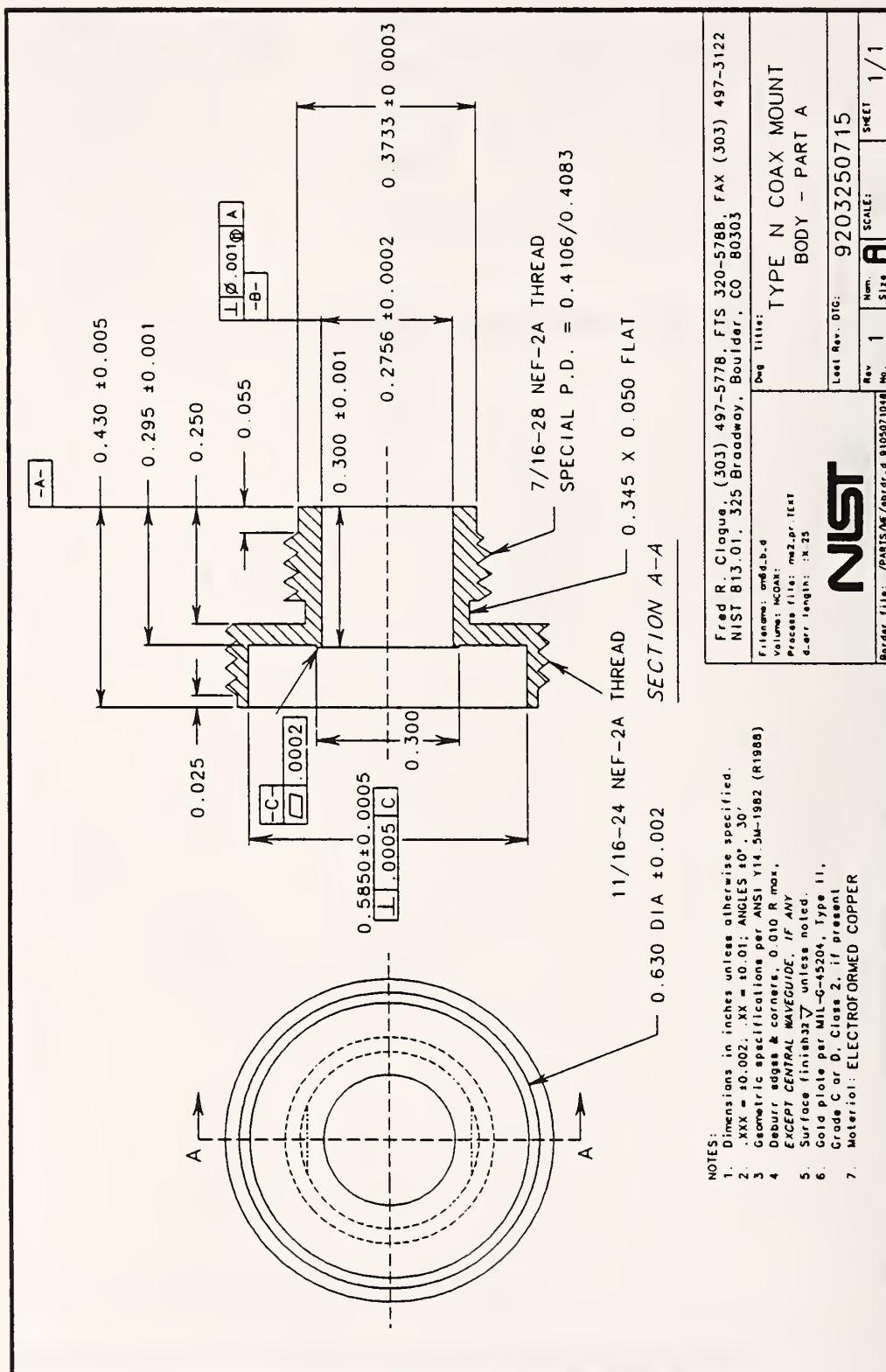
BOTTOM VIEW (As seen from inside the mount cap)



PIN 1: WHITE, LO-SIDE CURRENT  
PIN 2: GREEN, HI-SIDE CURRENT  
PIN 3: RED, HI-SIDE POTENTIAL  
PIN 4: BLACK, LO-SIDE POTENTIAL

**Figure B6.** Wiring convention for the dc bias connector, J1.

## APPENDIX C. Part Drawings Specific to Type N Mounts



**Figure C1. Body part A (Type N).**

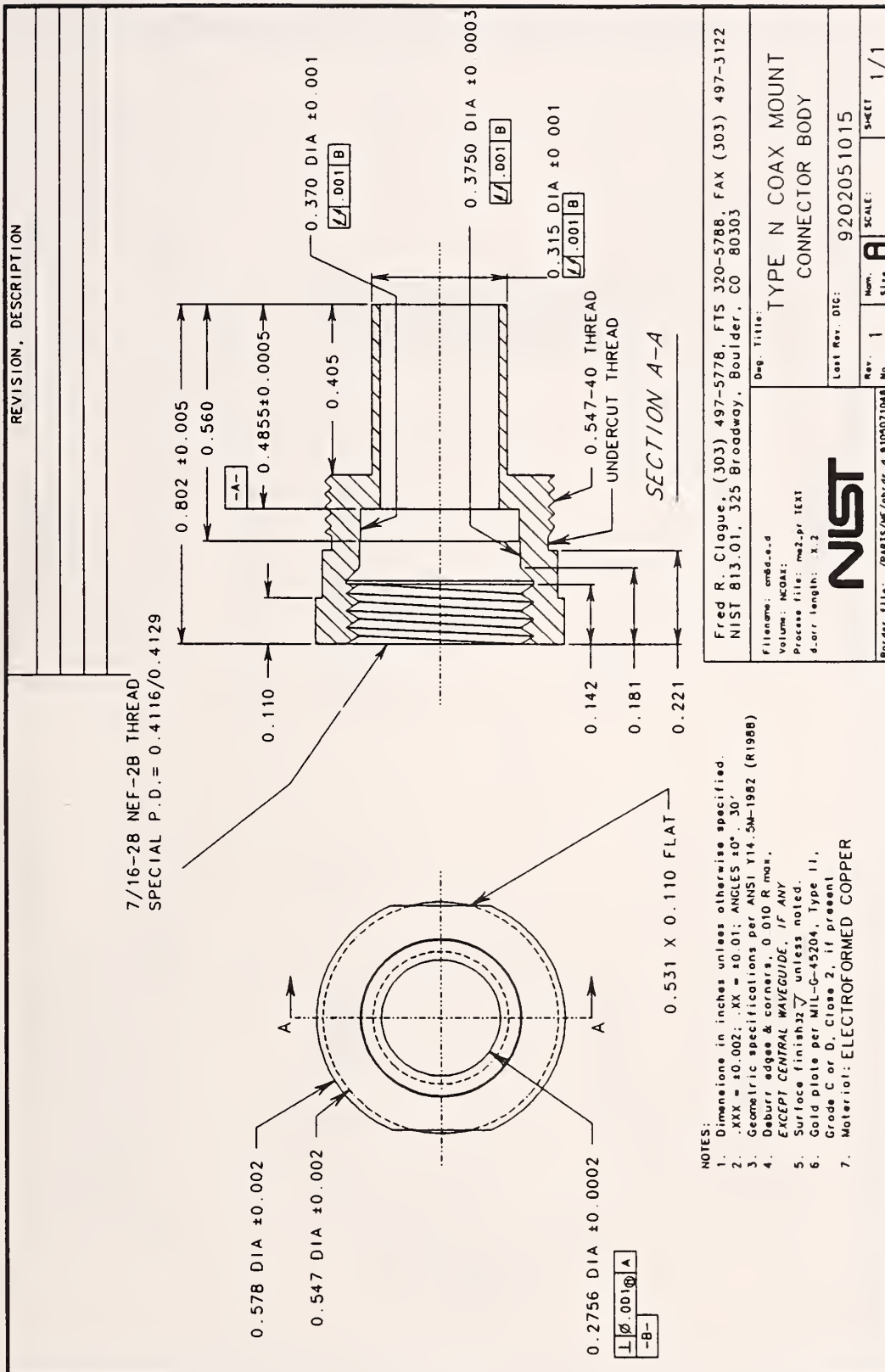


Figure C2. Connector body (Type N), part C2.

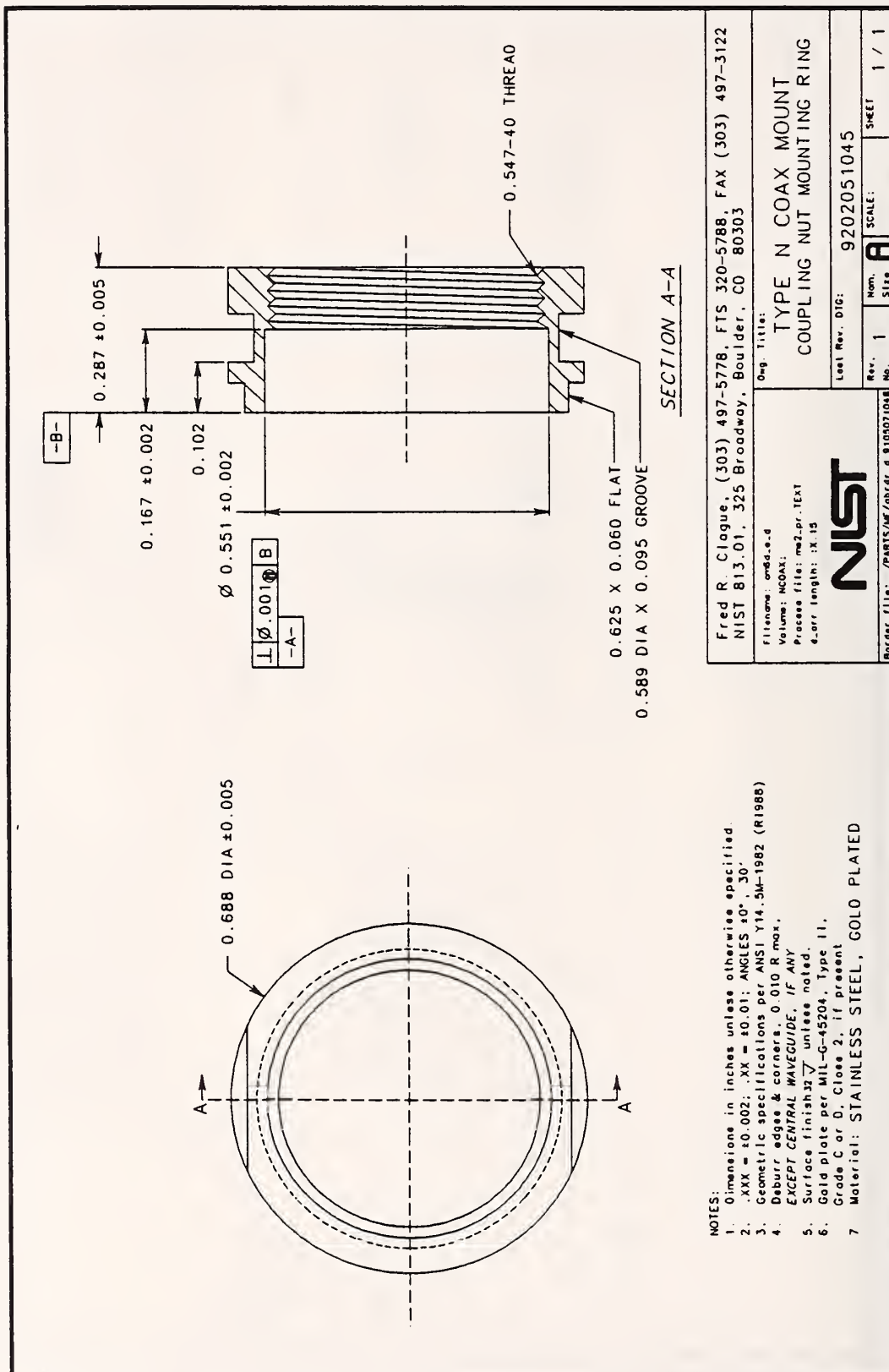


Figure C3. Coupling nut mounting ring (Type N), part C3.



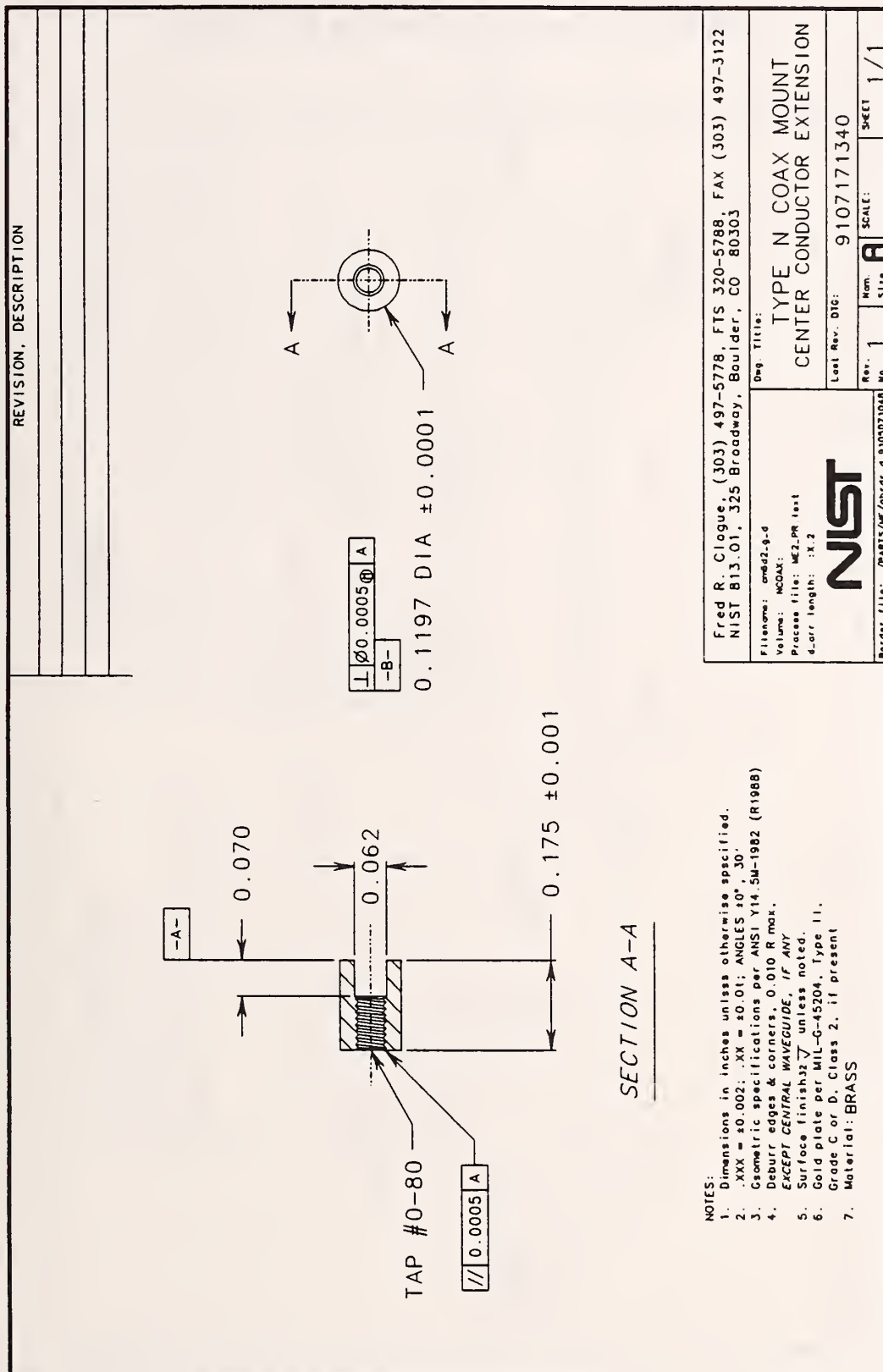


Figure C4. Center conductor extension (Type N), part C4.

## APPENDIX D. Part Drawings Specific to APC-7 Mounts

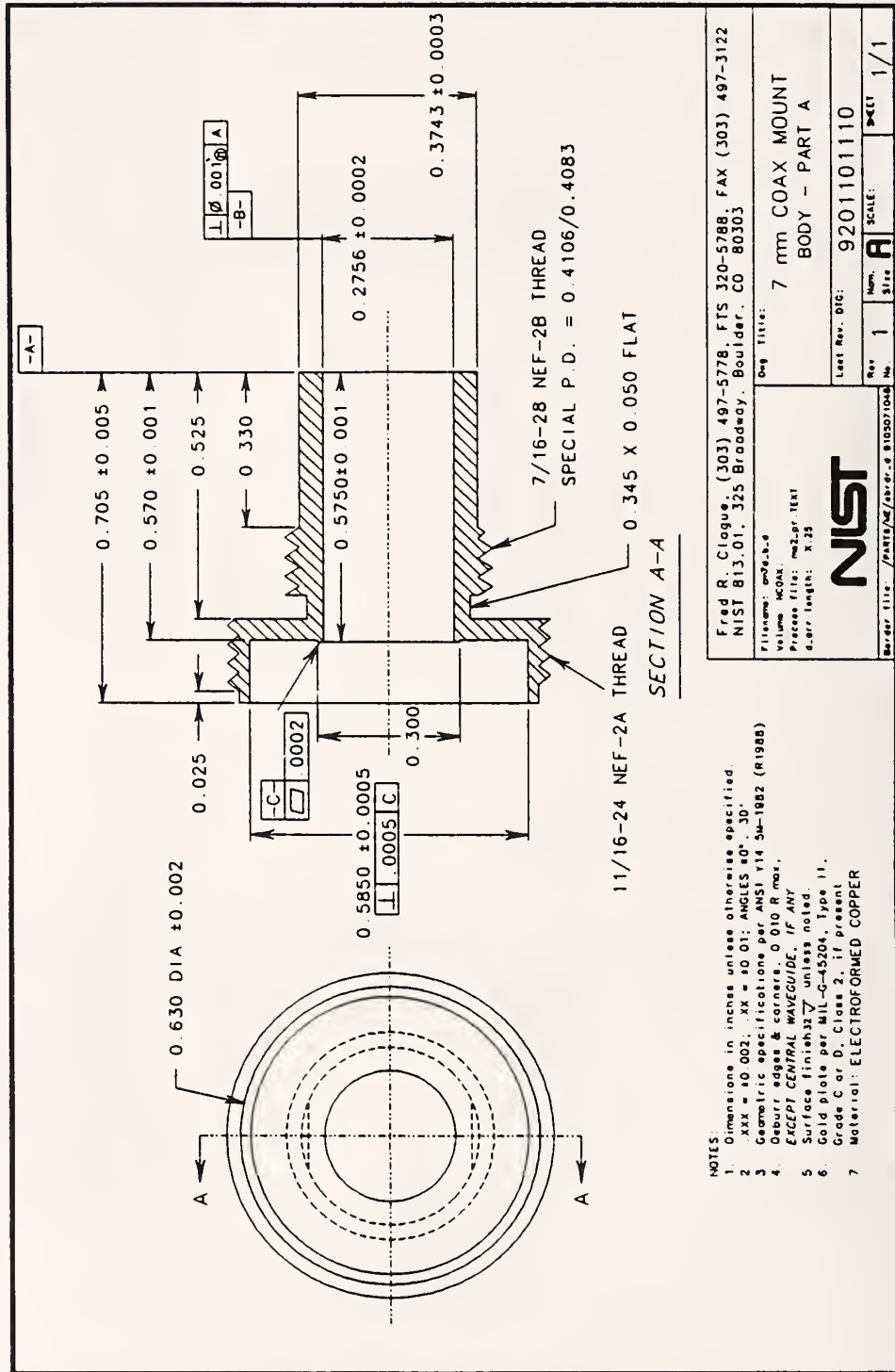


Figure D1. Body part A (APC-7).

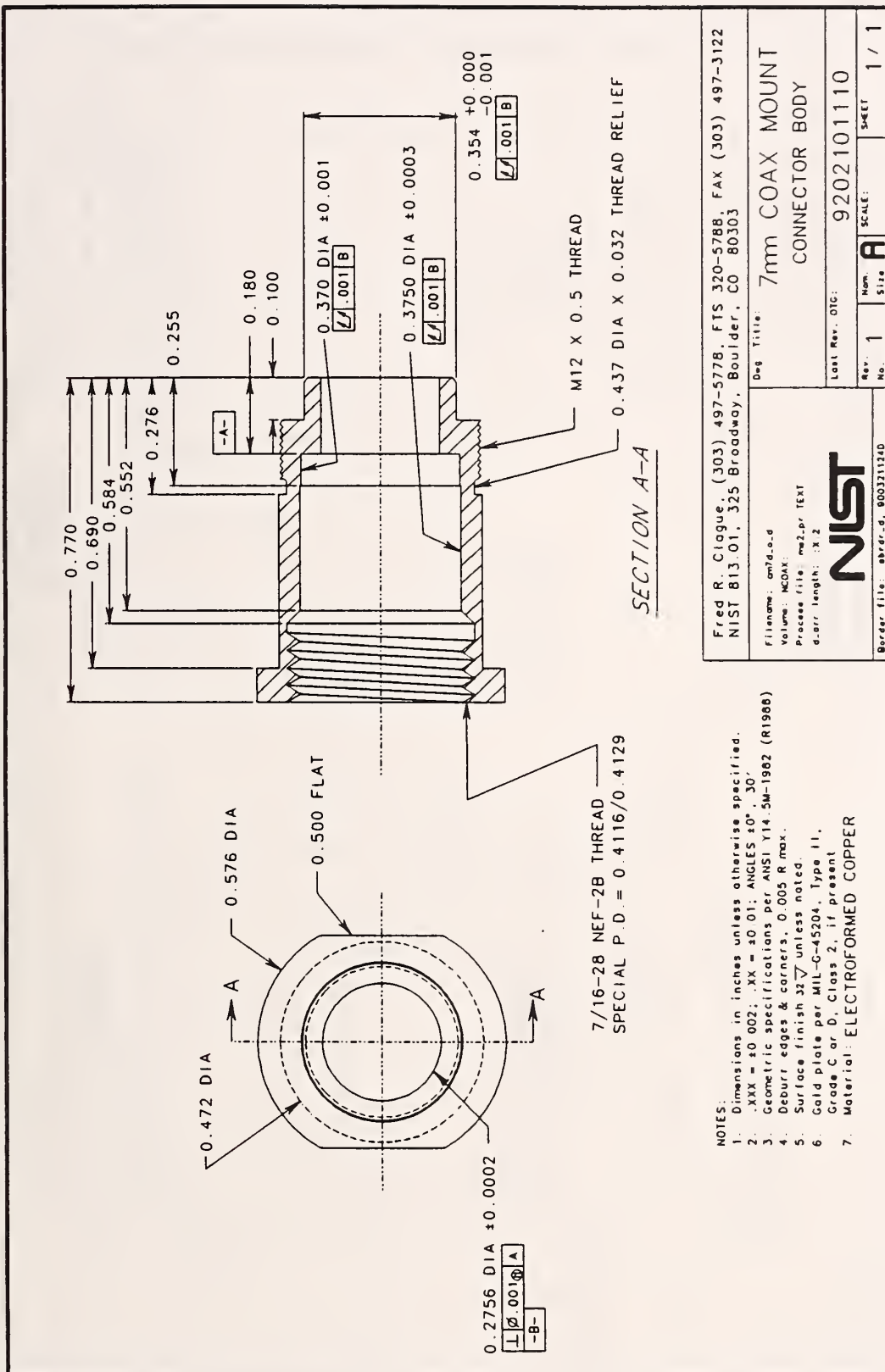


Figure D2. Connector body (APC-7), part D2.

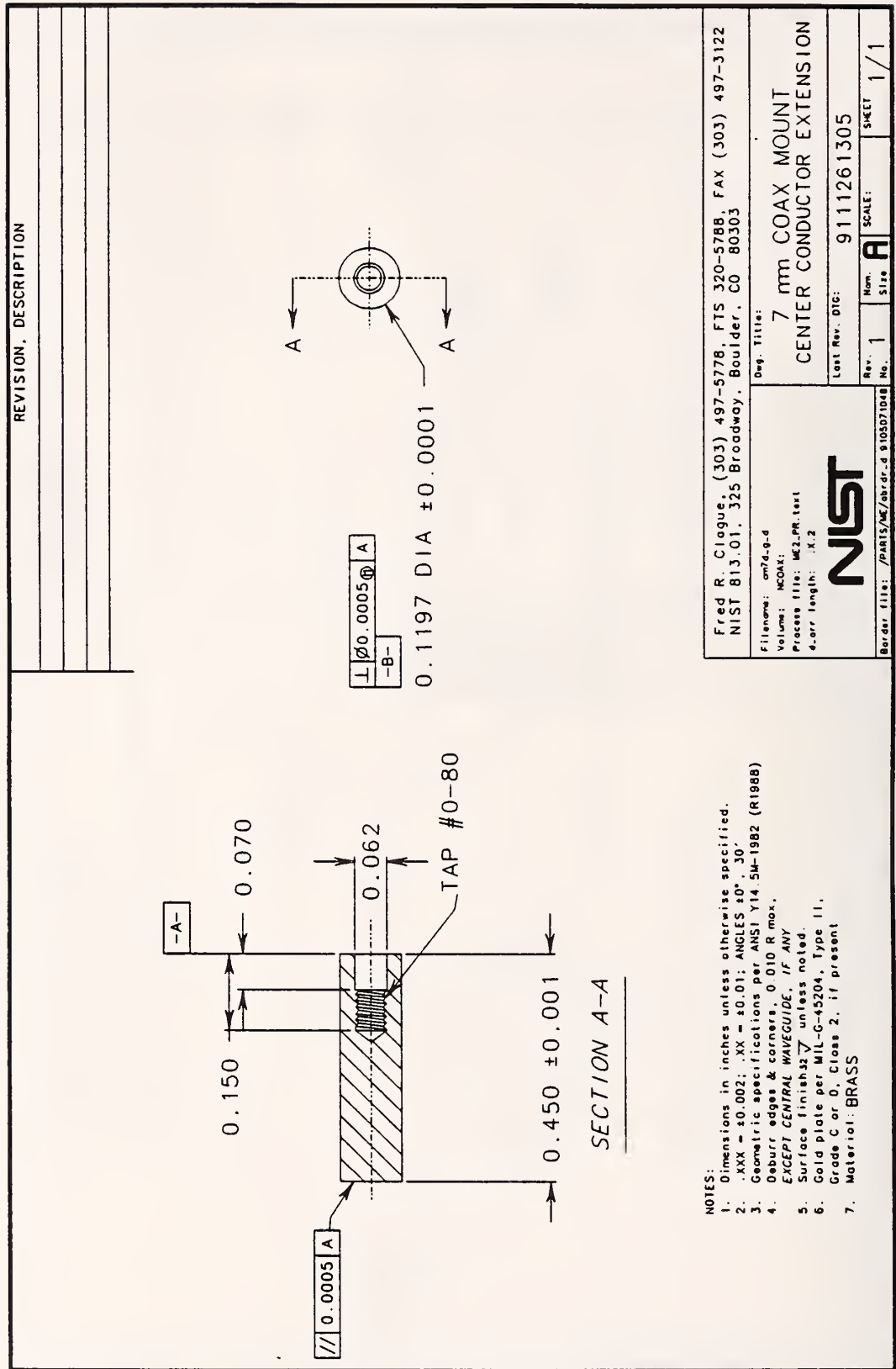
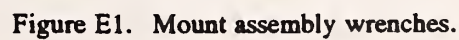


Figure D3. Center conductor extension (APC-7), part D3.



### Drawings for Special Assembly Tools and Microwave Absorber Fabrication



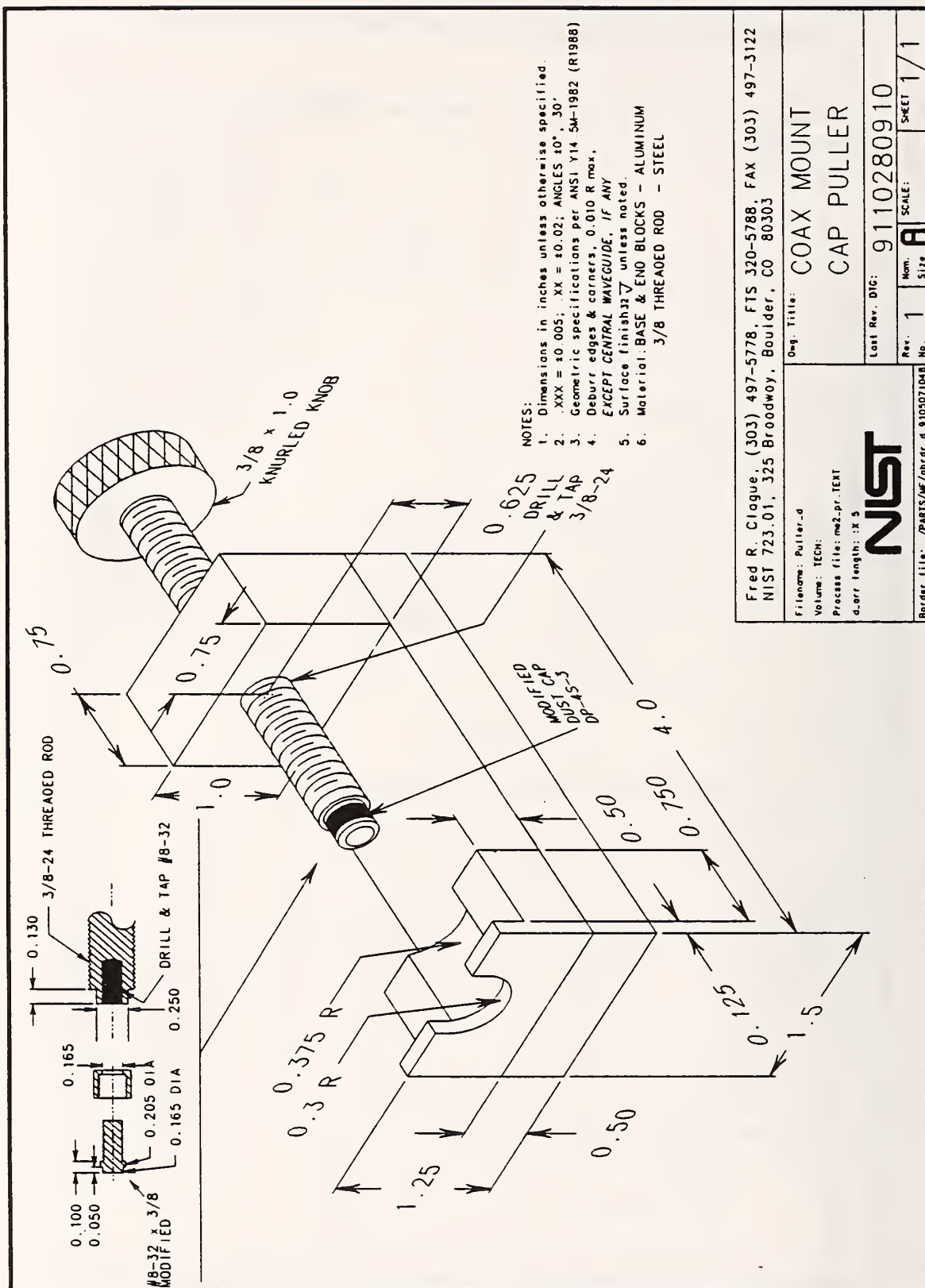


Figure E2. Mount cap puller, part E2.

## Microwave Absorber Fabrication

The following describes the steps necessary for the fabrication of the magnetic microwave absorbers used in the construction of the mount.

The microwave absorbers are made from a mixture of one part silicon rubber to four parts iron powder and are cast in a mold made as shown in figure E3. The supplies (with Table A.2 identification in parentheses), tools, and parts needed are listed below, followed by the fabrication steps.

1. Silicon rubber (S2)
2. Iron powder (S3)
3. Teflon mold and plugs (see figures E3 and E4)
4. Oven or hot plate
5. Vacuum chamber such as a bell jar and pump

- Step 1. Fill the six-mold array with plugs to obtain the configuration shown in figure E4. Use tape on bottom of mold to keep plugs from falling through.
- Step 2. Mix about 5 g of silicon rubber following the directions on the product data sheet.
- Step 3. Add 4 parts by mass of iron and mix thoroughly.
- Step 4. Place silicon/iron mixture in the vacuum chamber and pump until all or most outgassing has stopped.
- Step 5. Pour mixture into mold array, filling each cavity completely.
- Step 6. Place the filled mold under vacuum until most of the air bubbles are removed. Add more mixture if needed and level off top of mold. Remove as much excess as possible.
- Step 7. Bake filled mold at 100°C for 1 h.
- Step 8. Allow mold to cool, remove cured microwave absorbers by carefully pushing out the largest pegs from the bottom. Trim off any excess silicon rubber.

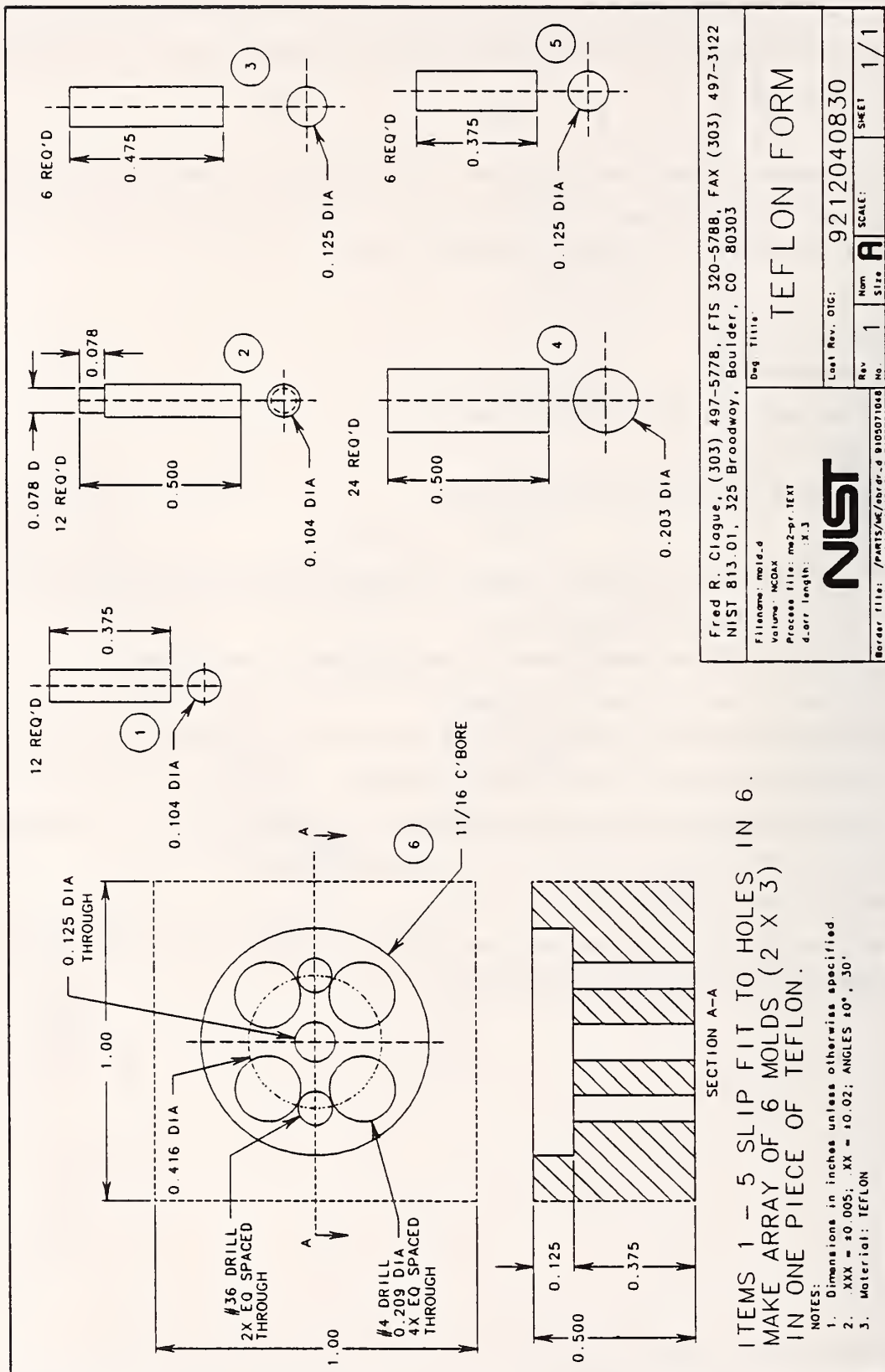
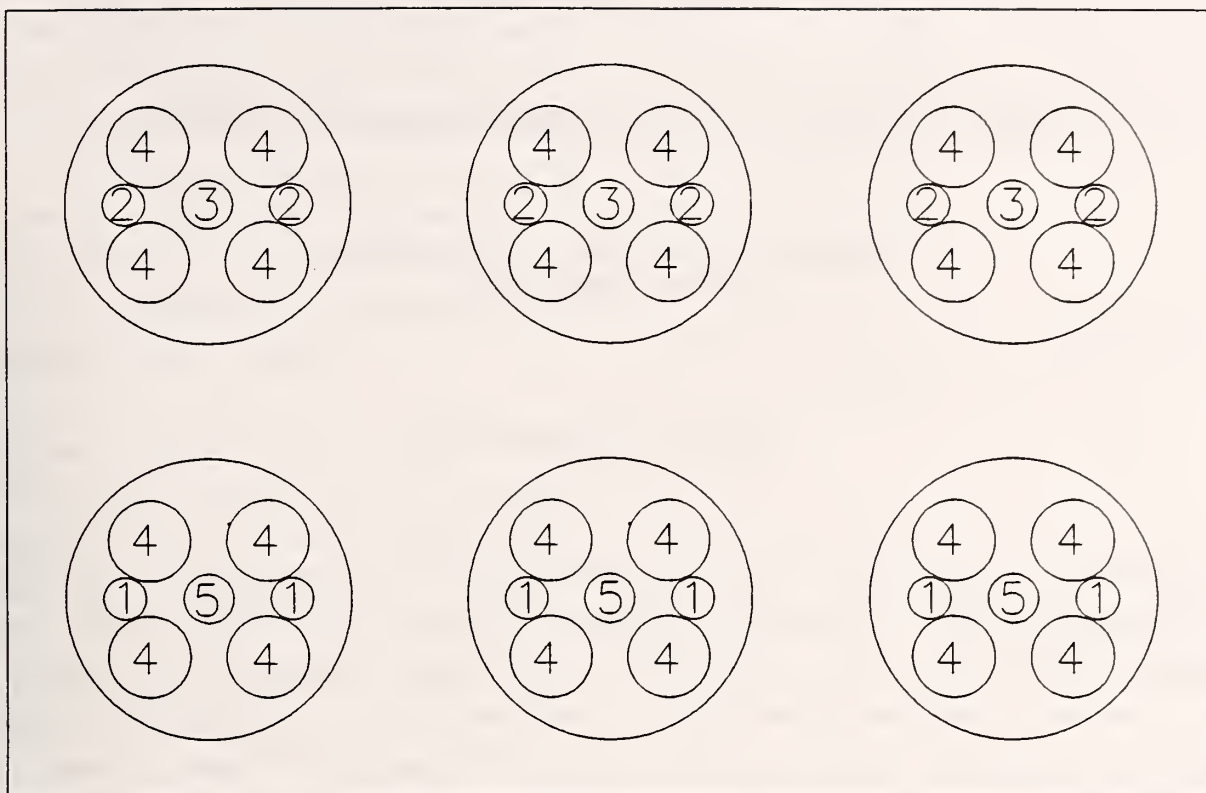


Figure E3. Mold for resonance suppressor.





**Figure E4.** Mold configuration for three sets of microwave absorbers, as viewed from above. Numbers denote which of the plugs, shown in figure E3, to use.

## APPENDIX F. Operating Manual

### MODEL CN COAXIAL MICROWAVE POWER REFERENCE STANDARD

National Institute of Standards and Technology  
Boulder, Colorado 80303

#### 1. GENERAL INFORMATION

The NIST Model CN coaxial microwave power reference standard is a 200  $\Omega$  thermistor mount especially designed to be calibrated directly in the NIST coaxial microcalorimeter. The mount is then used as the reference or transfer standard to calibrate lower echelon transfer instruments. Its physical characteristics are the result of the microcalorimeter-compatible design. These features are: a small size and mass so it can reach thermal equilibrium more quickly, a body made of copper with no thermal isolation (and no temperature compensation thermistors) for better thermal transfer to the microcalorimeter, and a better low pass filter on the dc bias leads to minimize rf leakage. In addition, four leads are brought into the mount very close to the thermistor beads to virtually eliminate lead resistance errors when used with the NBS Type IV power meter. The copper body with no thermal isolation makes the standard more sensitive to ambient temperature changes, so that more care must be exercised in the use of the mount than would be needed for a commercial general purpose thermistor mount. In addition, because of the copper body, the standard must be protected against any mechanical abuse such as blows or being dropped.

#### 2. SPECIFIC INFORMATION

The thermistor bead assembly (thermistor bulkhead) is a modified version of the bulkhead used in the HP Model 8478B thermistor mount. A copy of the manual for the 8478B is included with this manual. All of the precautions listed for mechanical shock, biasing, and maximum power input also apply to the Model CN. Note a difference in the dc connections to the thermistor beads: in the 8478B one side is connected to the mount body (unbalanced), while in the Model CN both sides float. This allows more flexibility to eliminate instrumentation ground loops.

Before mating the Model CN with any female Type N connector, be sure the critical dimension shown in figure 1 is within the indicated limits. Failure to observe the maximum limit could result in catastrophic damage to the mount. Also inspect both connectors before use for dirt or damage. Clean or replace the female connector as needed.

The mount connector, with its copper outer conductor, can be easily damaged. However, taking care to measure and inspect the mating connector, always using a torque wrench (approximately  $1.13 \text{ N} \cdot \text{m}$  ( $10 \text{ lbf} \cdot \text{in}$ )), keeping the connector clean, and not allowing the mount to rotate when connecting or removing it, will give maximum connector life. One NIST mount has well over 100 connections without any evidence of wear or damage.

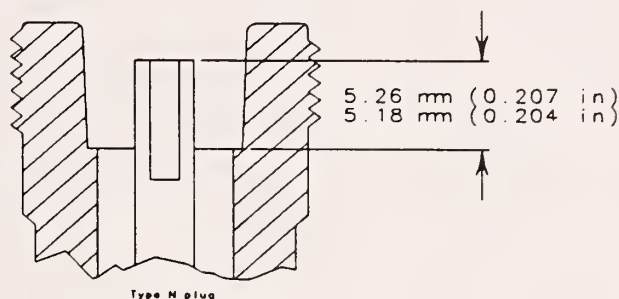


Figure 1. Dimension limits on female Type N connector.

The mount is designed to operate with an NBS Type IV power meter at a resistance of  $200 \Omega$ . Inadvertent operation at  $100 \Omega$  can result in damage to the thermistors. A four-conductor dc bias cable is supplied with the mount with either banana plugs or the appropriate connector for the power meter. Figure 2 shows the pin-out for the mount connector.

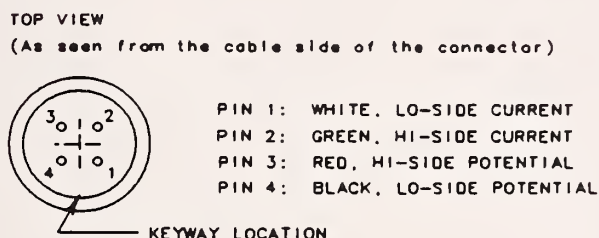


Figure 2. Mount bias connector pin-out.

Except for the cap, the mount is made of threaded parts that are mated. Special wrenches are generally required for the assembly (or disassembly) of the mount. However, none of the threaded parts are pinned to prevent turning, so it is possible for them to become loose. This is especially true for the largest part, the mount body, because it cannot be assembled with a wrench. Should any parts become loose, retighten the assembly by hand and exercise extra care to not torque the mount in such a way as to loosen the body. If the problem persists, the mount can be returned to NIST to be checked and tightened.

The rear cap on the mount is a sliding fit with the body.

***WARNING: Do not pull on or try to remove the cap!***

Normally, it is not possible to remove the cap by hand. However, in some mounts the fit is not as tight, so an inadvertent pull may partially or totally remove the cap. If the cap is partially removed, it can simply be pressed back into the body. If the cap is completely removed, it must be replaced in the correct orientation. The notch (keyway) on the miniature dc bias connector is aligned between either one of the shorted internal connector pairs. See figure 3. The shorted pairs are determined with an ohm-meter.

The operating frequency range is 50 MHz to 18 GHz. The measured effective efficiency data are supplied for this range. The effective efficiency measurement is valid only at the 10 mW power used in the microcalorimeter. When using the mount to calibrate a transfer instrument it must be done at 10 mW. This is primarily because the reference standard is a dual-element coaxial thermistor mount and subject to a power nonlinearity known as the dual-



element error. This error is included in the effective efficiency as measured in the microcalorimeter at 10 mW, but at lower powers, such as 1 mW, it will add a systematic uncertainty that cannot be calculated or easily measured.

As part of the initial NIST tests on a transfer standard, the reflection coefficient is measured using a network analyzer. A copy of an SWR plot from this measurement is included with the mount. This plot is only intended to show that the mount is within the manufacturer's specifications. The plot is not intended as a means to calculate the calibration factor. If the calibration factor is required, you will need to make your own measurement, adding the appropriate uncertainties.

The mount serial number is engraved on the cap.

***WARNING: Do not add marks or attach any labels to the mount!***

Marks or labels on the outside of the mount change its thermal characteristics and will prevent it from being calibrated in the microcalorimeter.

Because the mount is made of copper and has no thermal isolation, it is very sensitive to external temperature changes. However, these same factors and its small mass allow it come to thermal equilibrium with the equipment it is connected to fairly quickly. The following should be done to minimize the temperature induced bias drift and its effect:

- (1) use the mount in a temperature controlled lab,
- (2) keep it out of drafts,
- (3) use the supplied external insulating sleeve,
- (4) handle it with gloves,
- (5) wait several minutes after connecting it before making measurements, and
- (6) automate the mount voltage measurement so the drift can be corrected (make two rf-off readings, one before and one after the rf-on reading, and use linear interpolation to calculate an rf-off value as it would have been at the time of the rf-on reading).

Such measures have been adequate at NIST when using the mount with the six-port transfer instruments.

No schedule for calibration of the standard has been established. Until some history is accumulated, it is recommended the mount be recalibrated the first time within one year.

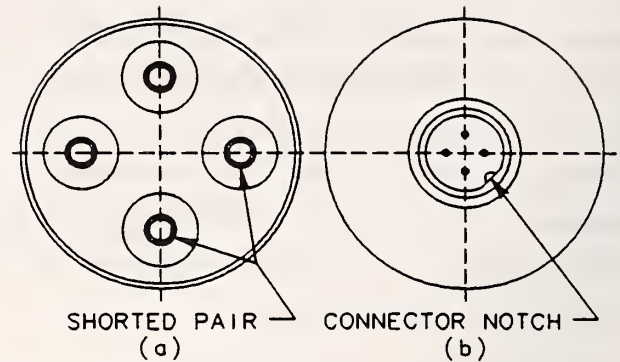


Figure 3. (a) End view of the mount with cap removed. (b) End view of the cap.



# *NIST* Technical Publications

## *Periodical*

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**Journal of Research of the National Institute of Standards and Technology**—Reports NIST research and development in those disciplines of the physical and engineering sciences in which the Institute is active. These include physics, chemistry, engineering, mathematics, and computer sciences. Papers cover a broad range of subjects, with major emphasis on measurement methodology and the basic technology underlying standardization. Also included from time to time are survey articles on topics closely related to the Institute's technical and scientific programs. Issued six times a year.

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**Special Publications**—Include proceedings of conferences sponsored by NIST, NIST annual reports, and other special publications appropriate to this grouping such as wall charts, pocket cards, and bibliographies.

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